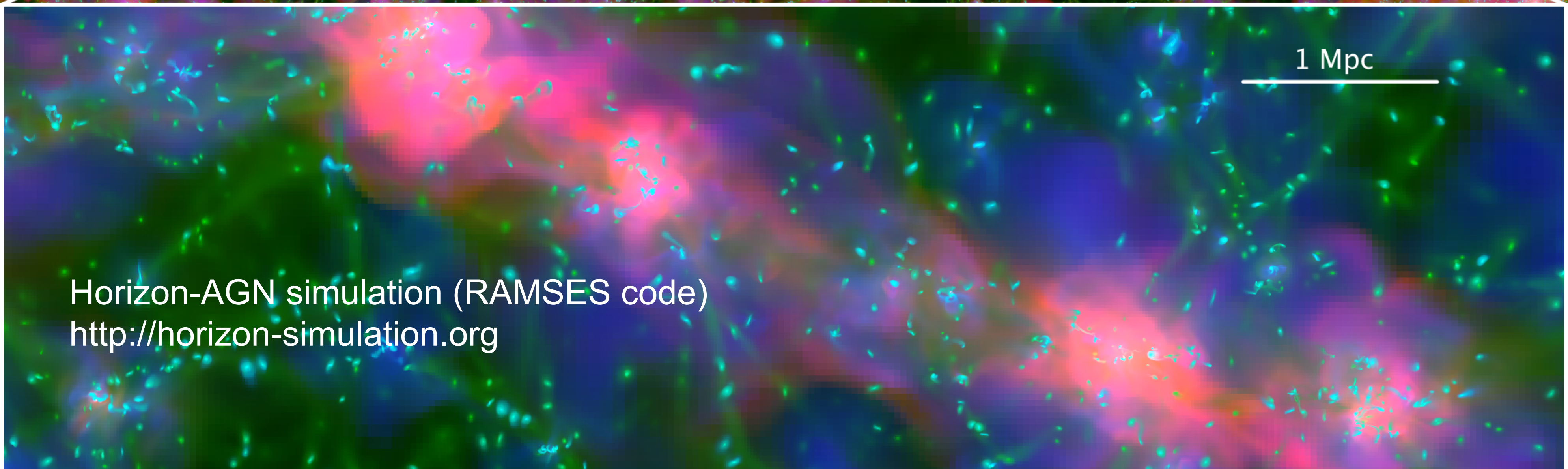
10 Mpc z=1.2

Growing high-z BHs with SN and AGN self-regulation

(why it's not so easy to grow big)

Yohan Dubois – Institut d'Astrophysique de Paris (IAP)

Collaborators:
Rebekka Bieri, Julien Devriendt, Mélanie Habouzit, Sugata Kaviraj,
Taysun Kimm, Clotilde Laigle, Christophe Pichon, Joki Rosdahl, Joe Silk, Adrianne Slyz,
Romain Teyssier, Marta Volonteri



Horizon-AGN simulation (RAMSES code)
http://horizon-simulation.org

Growing the first bright quasars

<u>Observationnal facts</u>:

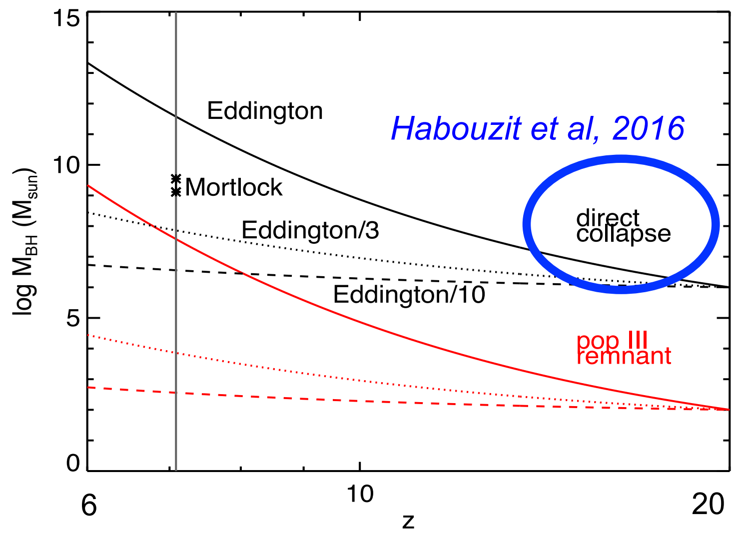
- Very bright quasars in the SDSS with z>6
(Willott et al., 2003; Fan et al., 2006; Jiang et al., 2009)
- Detection of a 2.10^9 M_{sun} BH at z=7
(Mortlock et al., 2011)

<u>Requirement</u>:

- Need to grow from 10^5-10^6 M_{sun} up to 10^9 M_{sun} in less than 700 Myrs ! Eddington limit provides an e-folding time = 45 Myr

<u>Question</u>:

- How to bring gas sufficiently rapidly into the bulge of the galaxy ?

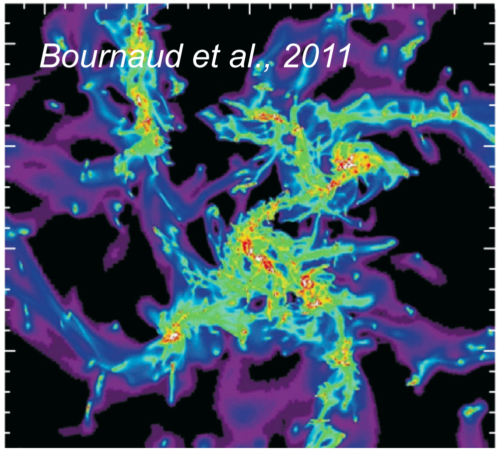


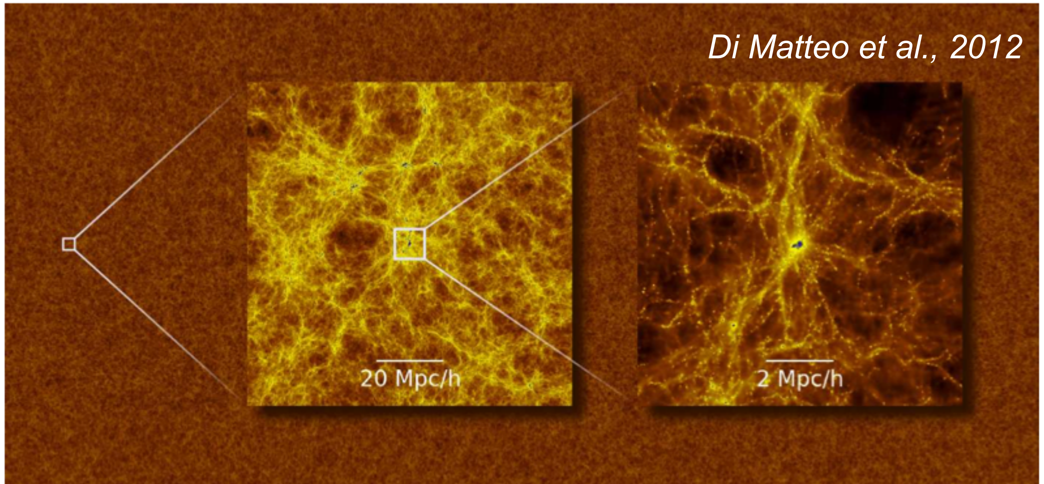
Growing the first bright quasars

- Direct accretion from the cosmic cold flows *(Di Matteo et al., 2012)*
Cosmological context with large statistics but low resolution (~1kpc)

Versus

- Violent disc instabilities *(Bournaud et al., 2011)*
High resolution (1pc) but isolated disc





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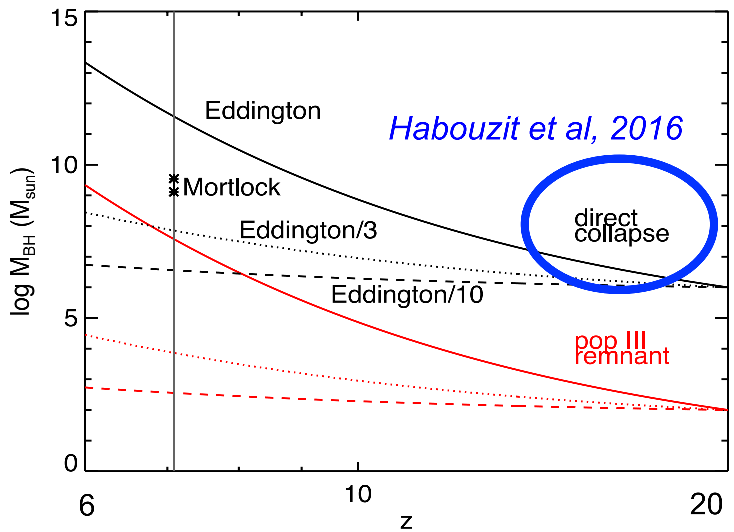

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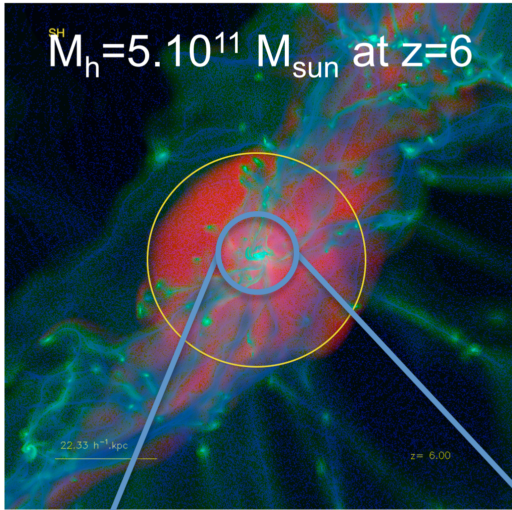
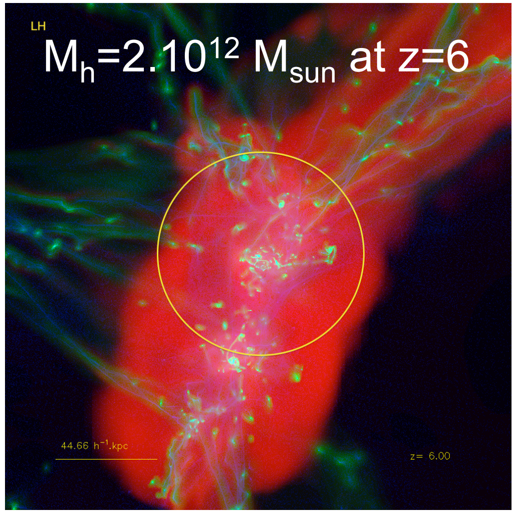
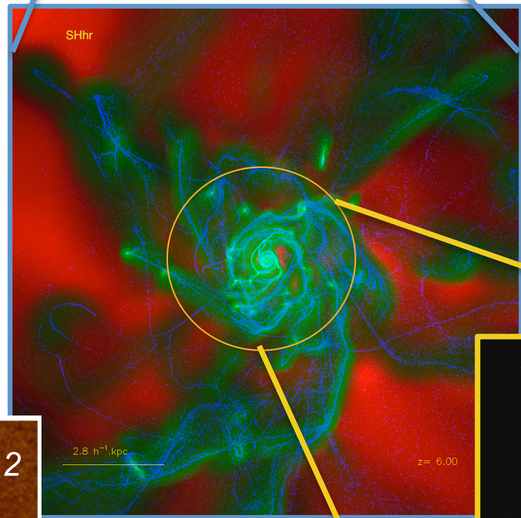
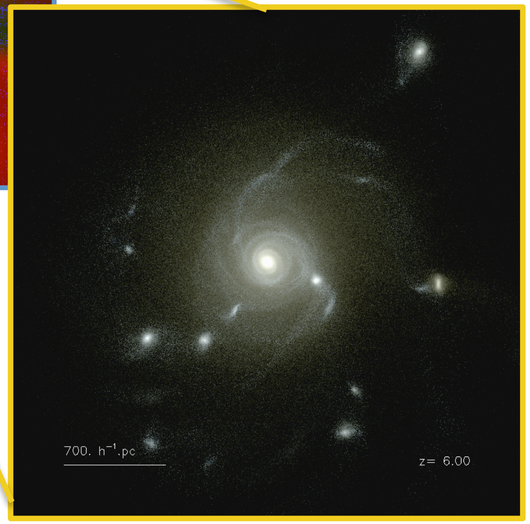


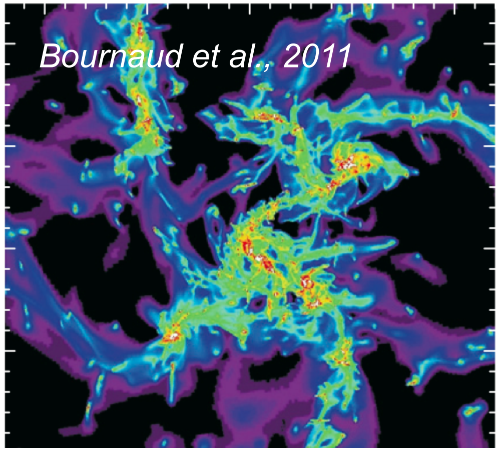


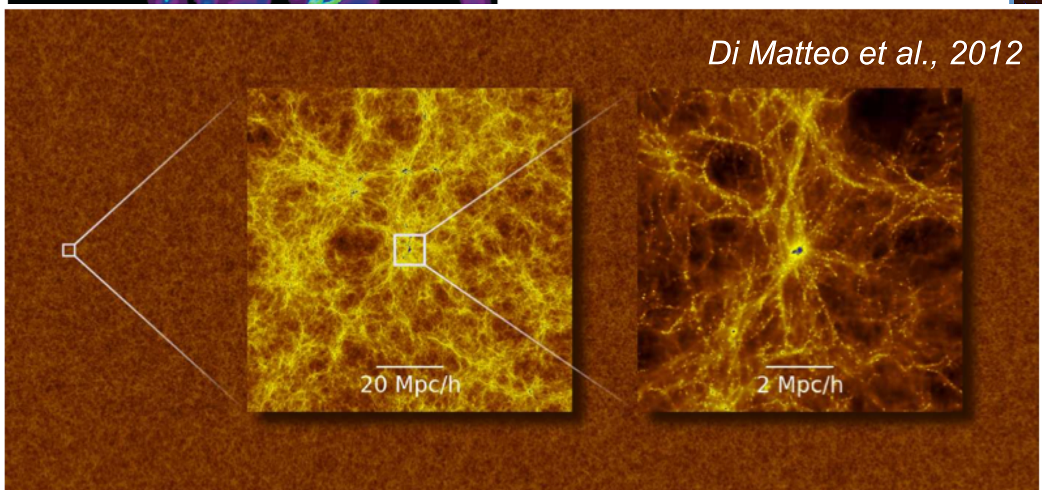




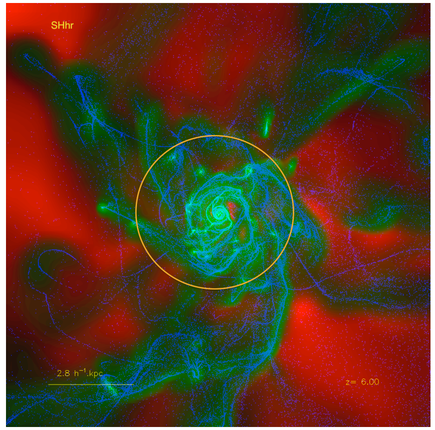
Cosmological zooms
10 pc resolution

Dubois, Pichon, Haehnelt et al., 2012

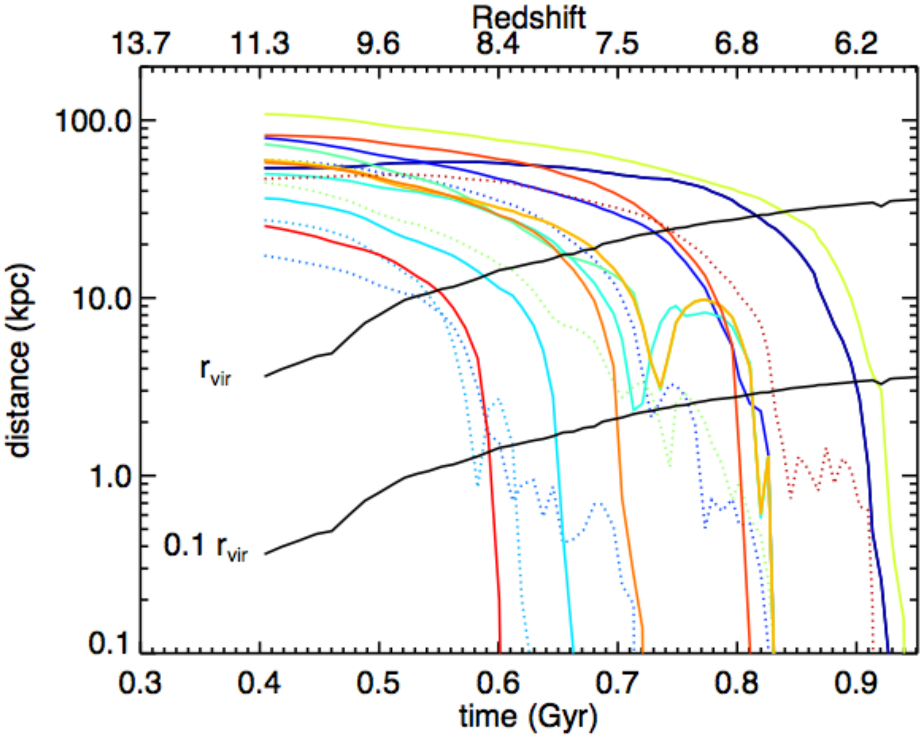


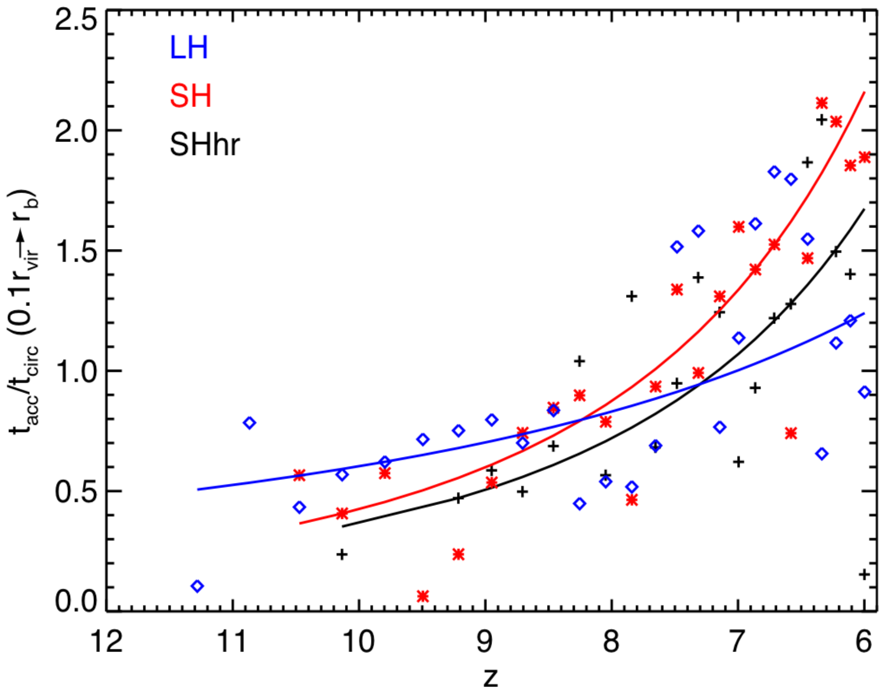


Follow the white rabbit



Take the gas tracer particles that belong to the galactic bulge

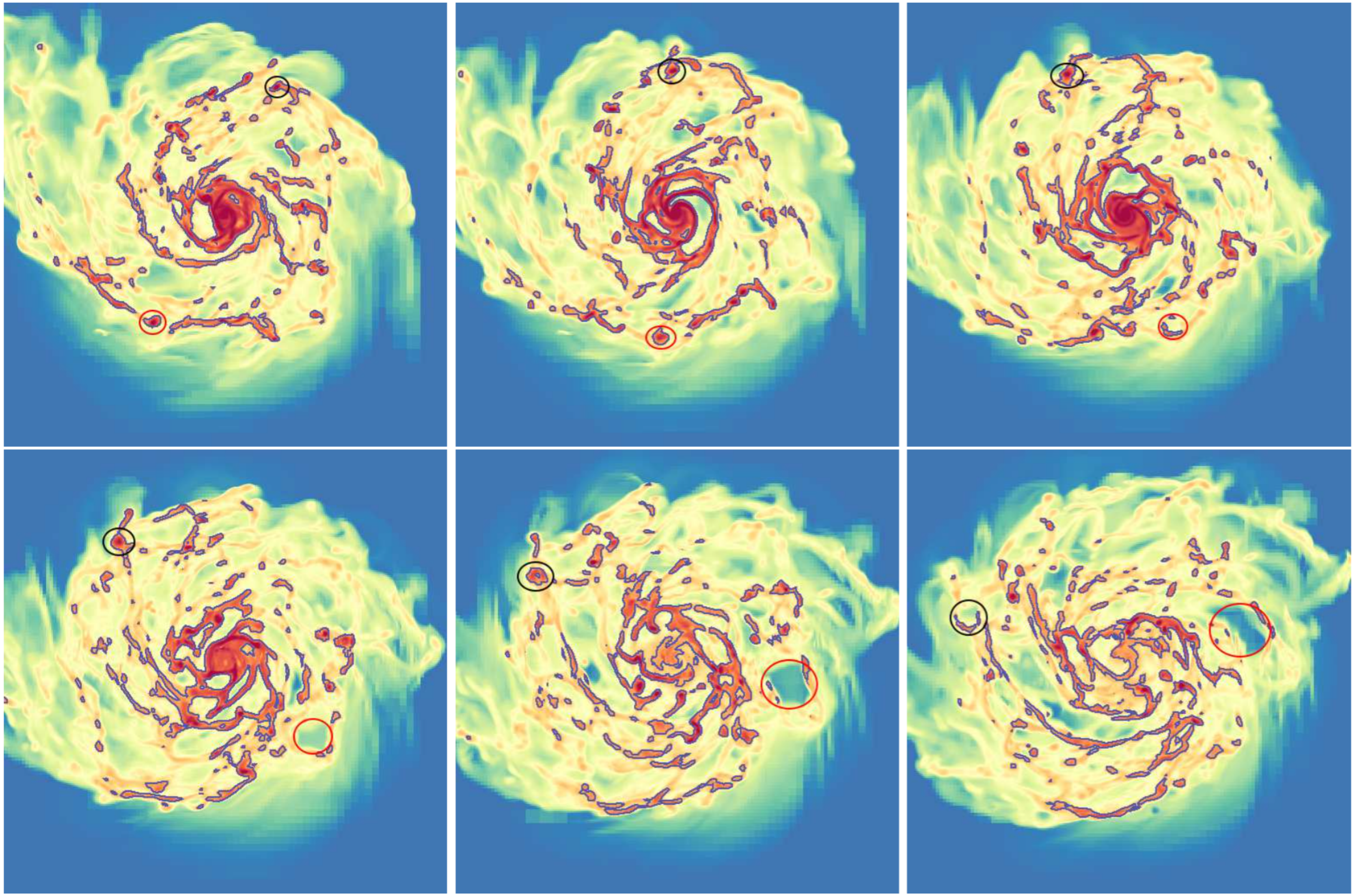




Dubois, Pichon, Haehnelt et al., 2012

Late time gas infall do more rotations before being accreted.
Compatible with late-time cosmic filamentary infall having more angular momentum (Pichon et al., 2011, Kimm et al., arXiv:1106.0538, Codis et al., 2012)

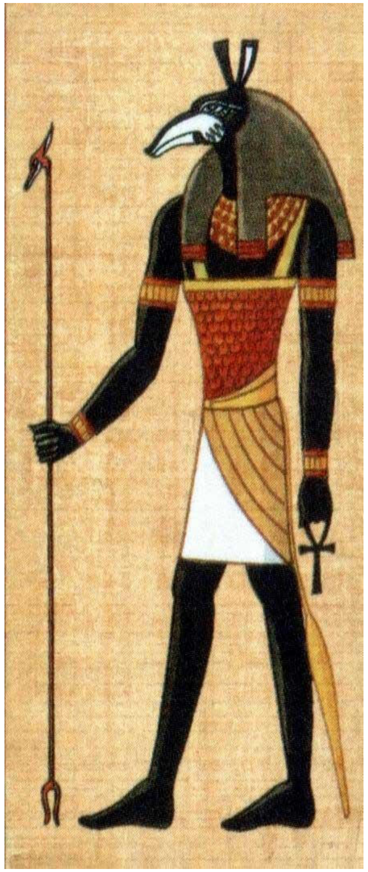
Does the SF clump destruction have any impact on BH growth?



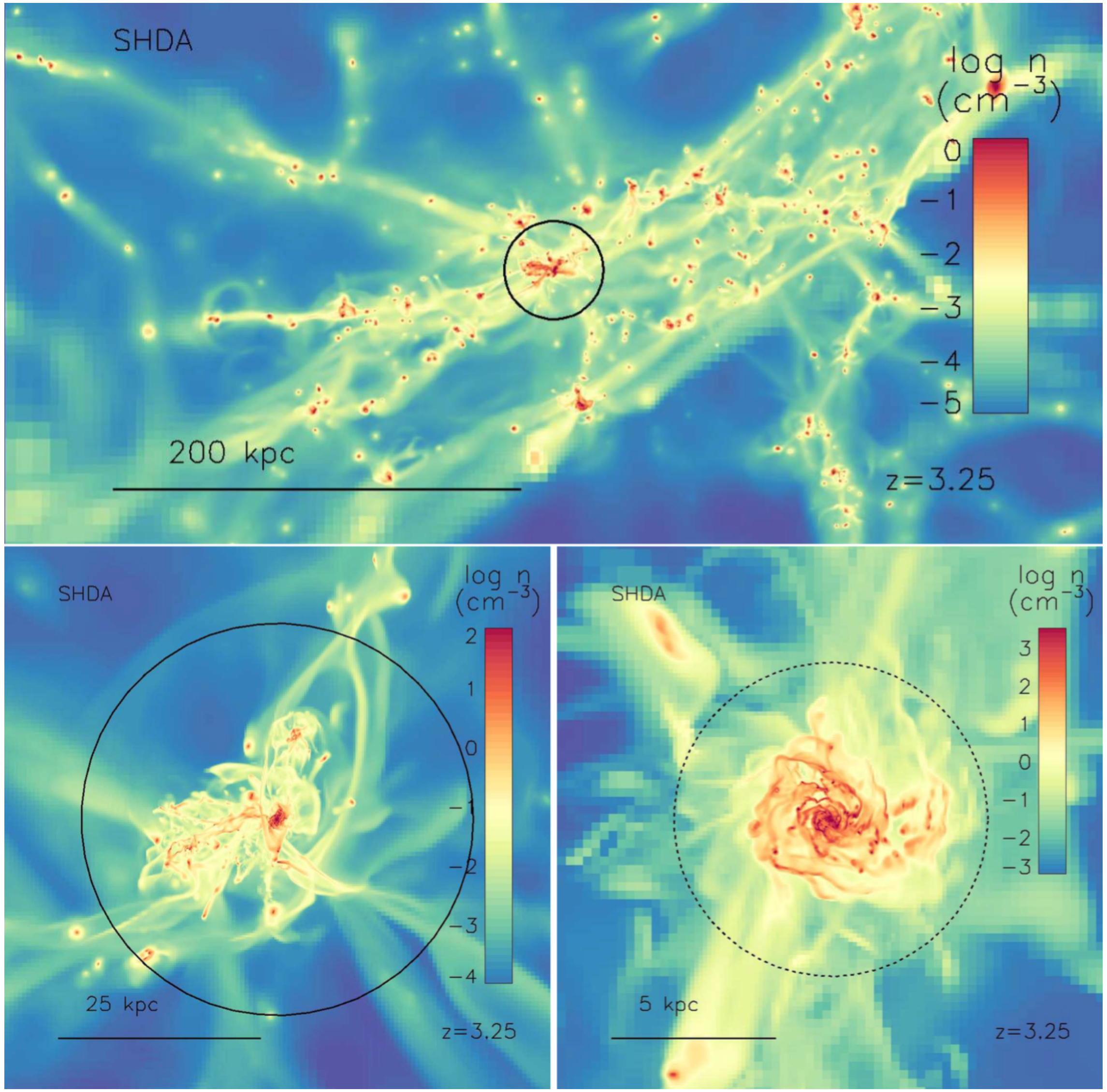
Dubois et al., 2014

Seth simulation

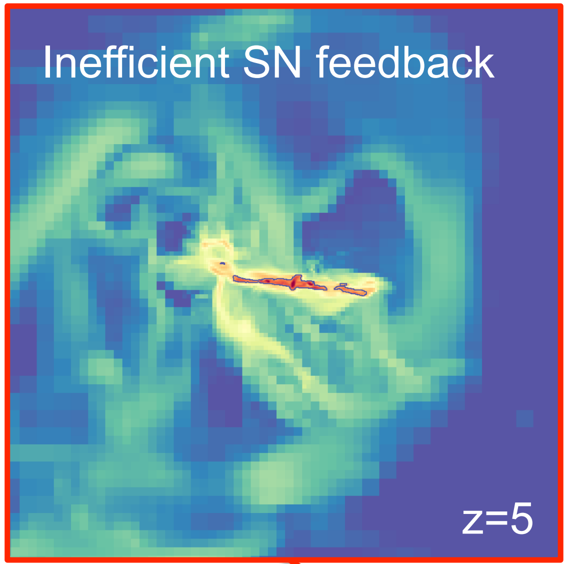
$M_h=10^{12}\ M_{sun}$ @ $z=2$
$M_{DM,res}=10^5\ M_{sun}$
$dx=10$ pc

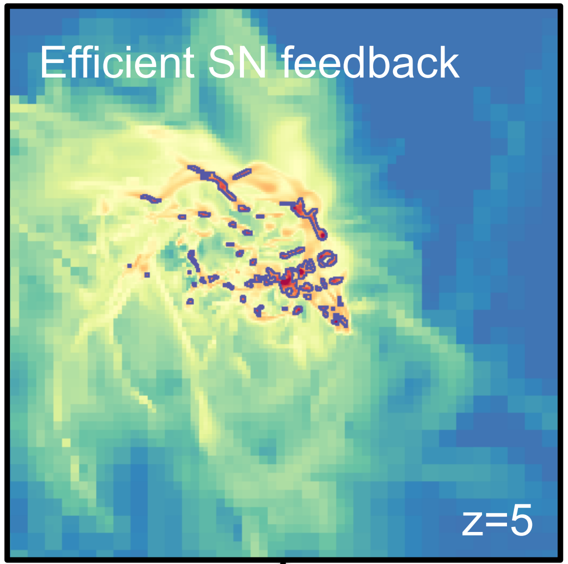


God of death, conflict, storms



BH growth delayed by efficient SN feedback



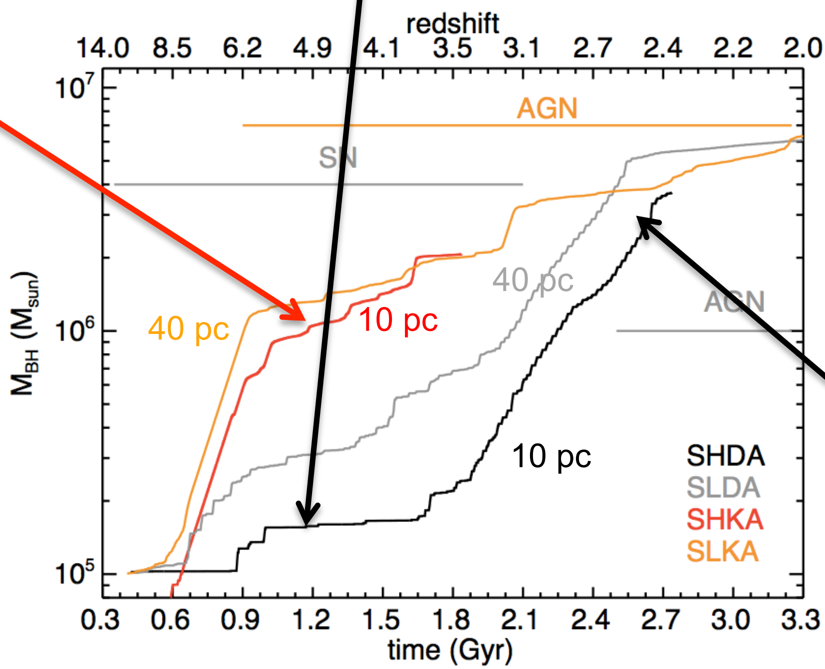


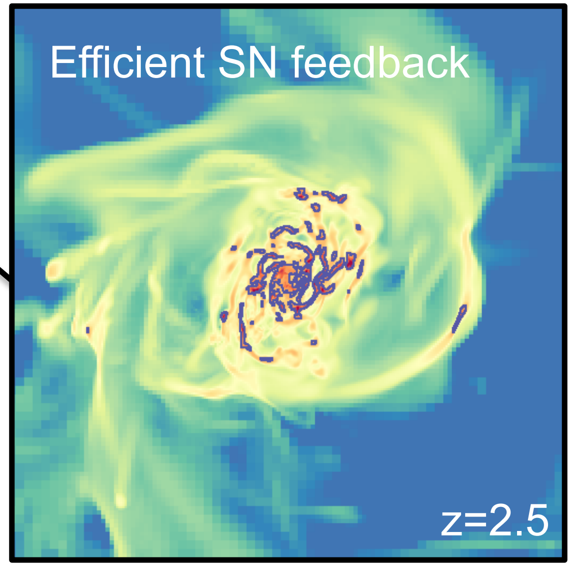
Bondi-capped-at-Eddington accretion rate
AGN quasar heating $f_{Edd}>0.01$
AGN radio jets $f_{Edd}<0.01$
(Dubois et al, 2012)

+BH spin evolution with spin-dependent radiative efficiency (and Eddington accretion rate)
(Dubois et al, 2014)

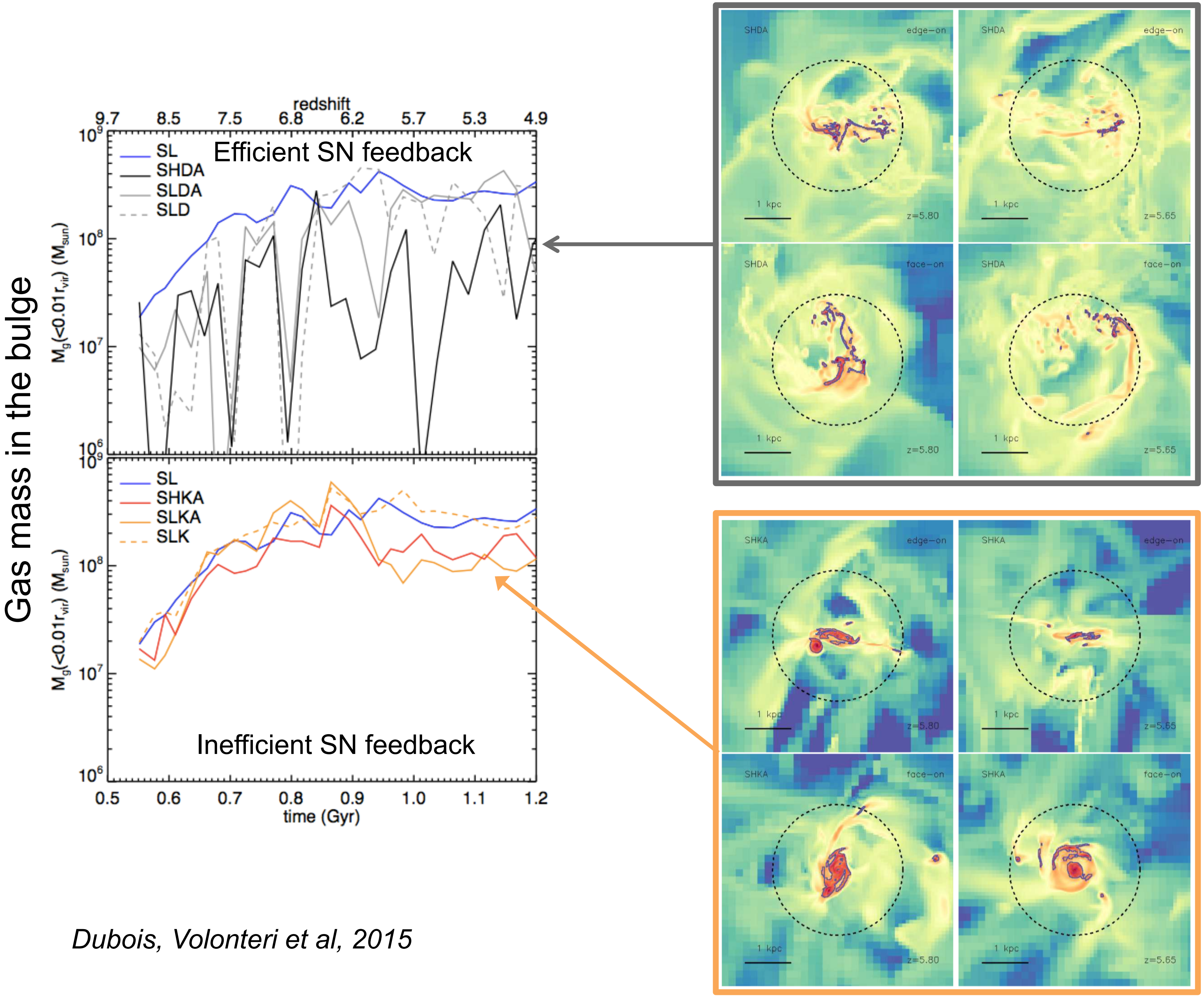
"Inefficient": kinetic blast wave model (Dubois & Teyssier, 2008)

"Efficient": non-thermal component (CR, turbulence, magnetic fields) that delays gas cooling (Teyssier et al, 2013)





Dubois, Volonteri et al, 2015

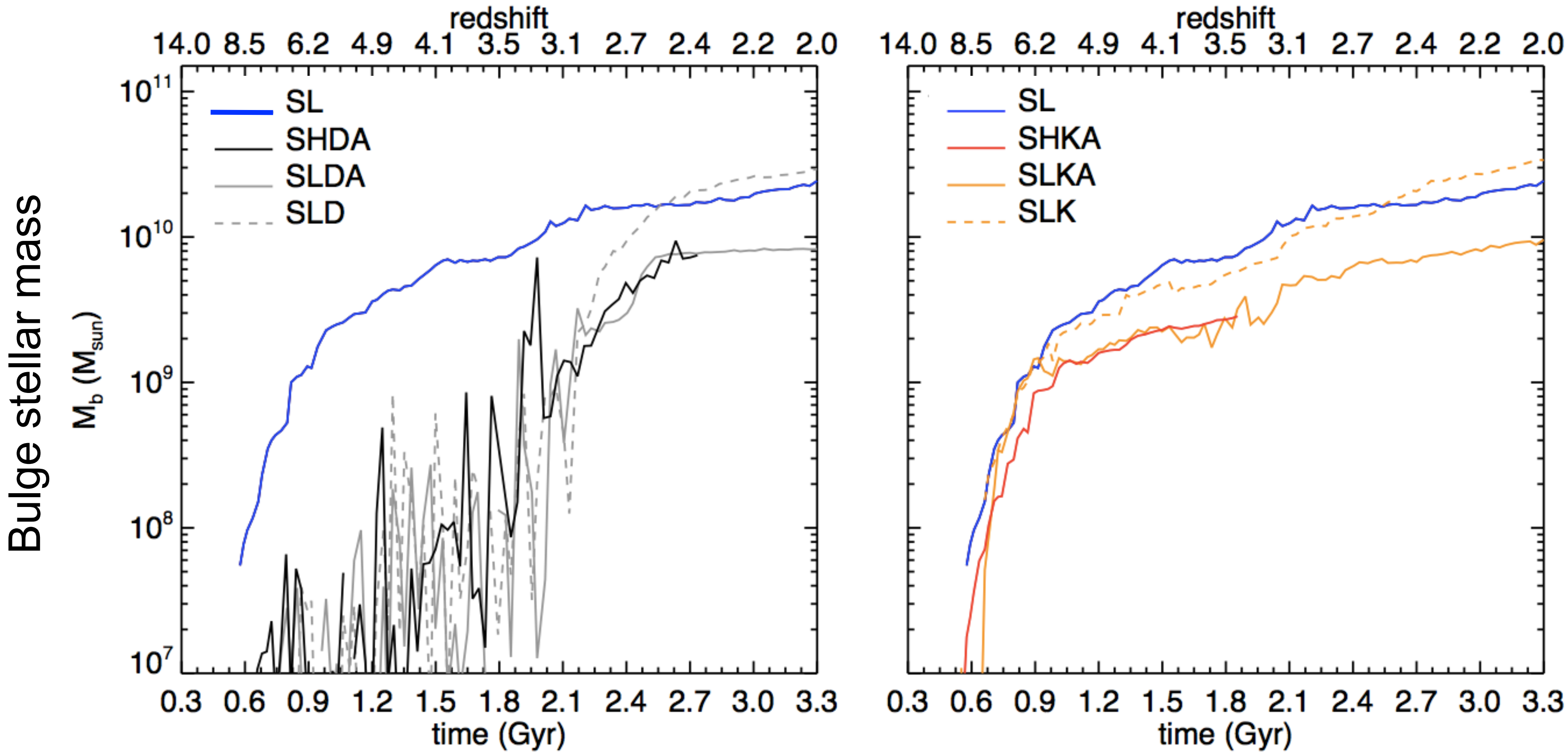


Dubois, Volonteri et al, 2015

$$u_{\rm SN} = 1.2\sqrt{\frac{m_{\rm new,s}\eta_{\rm SN}e_{\rm SN}}{m_{\rm g}}} \simeq 270\sqrt{\frac{\eta_{\rm SN}}{0.1}}\sqrt{\frac{(m_{\rm new,s}/m_{\rm g})}{0.1}}\,{\rm km\,s^{-1}}$$

$$u_{\rm esc} = \sqrt{\frac{2Gm_{\rm cl}}{r_{\rm cl}}}$$ ~ 300 km s^{-1}

For $m_{cl}=10^9$ M_{sun} and $r_{cl}=100$ pc



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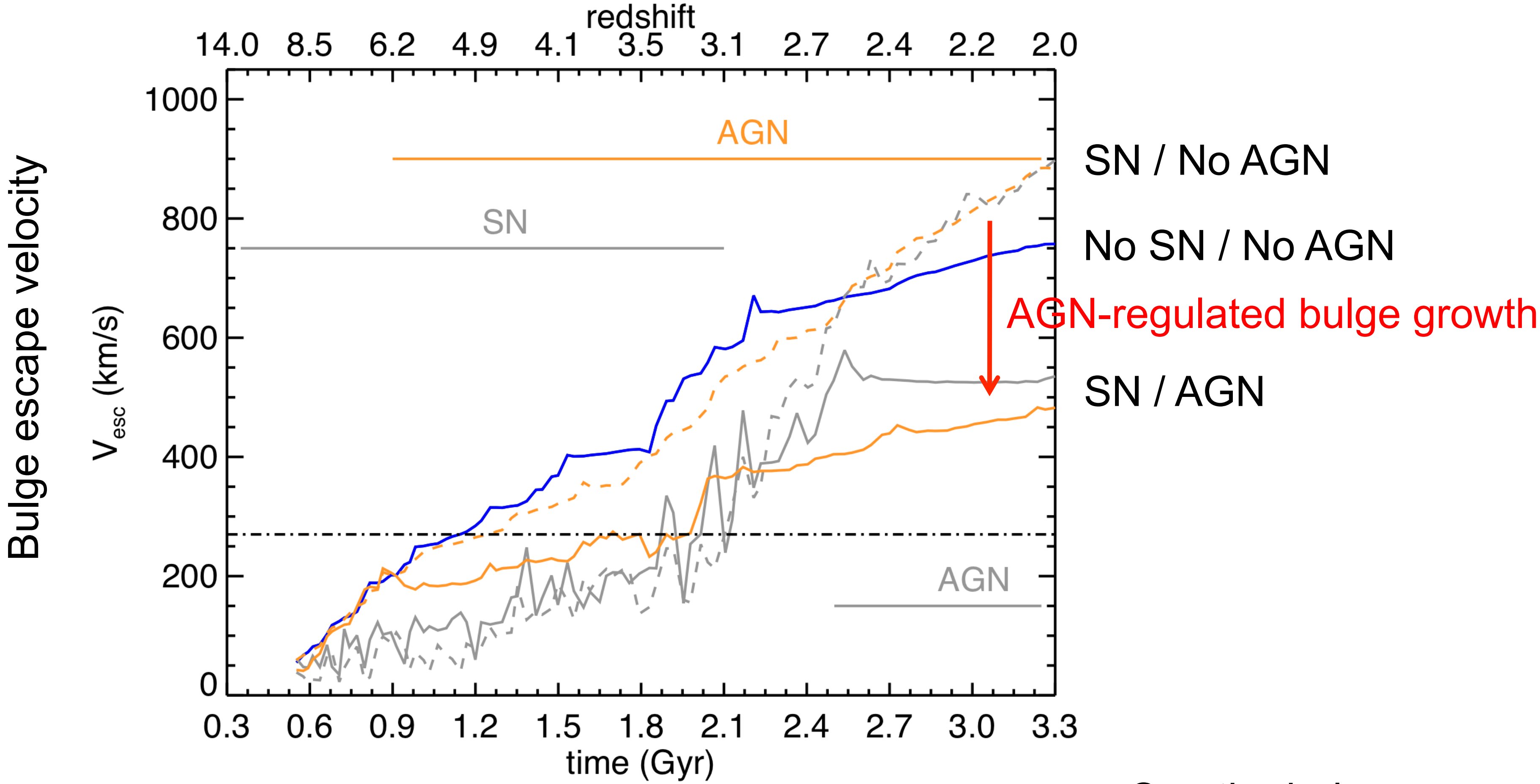
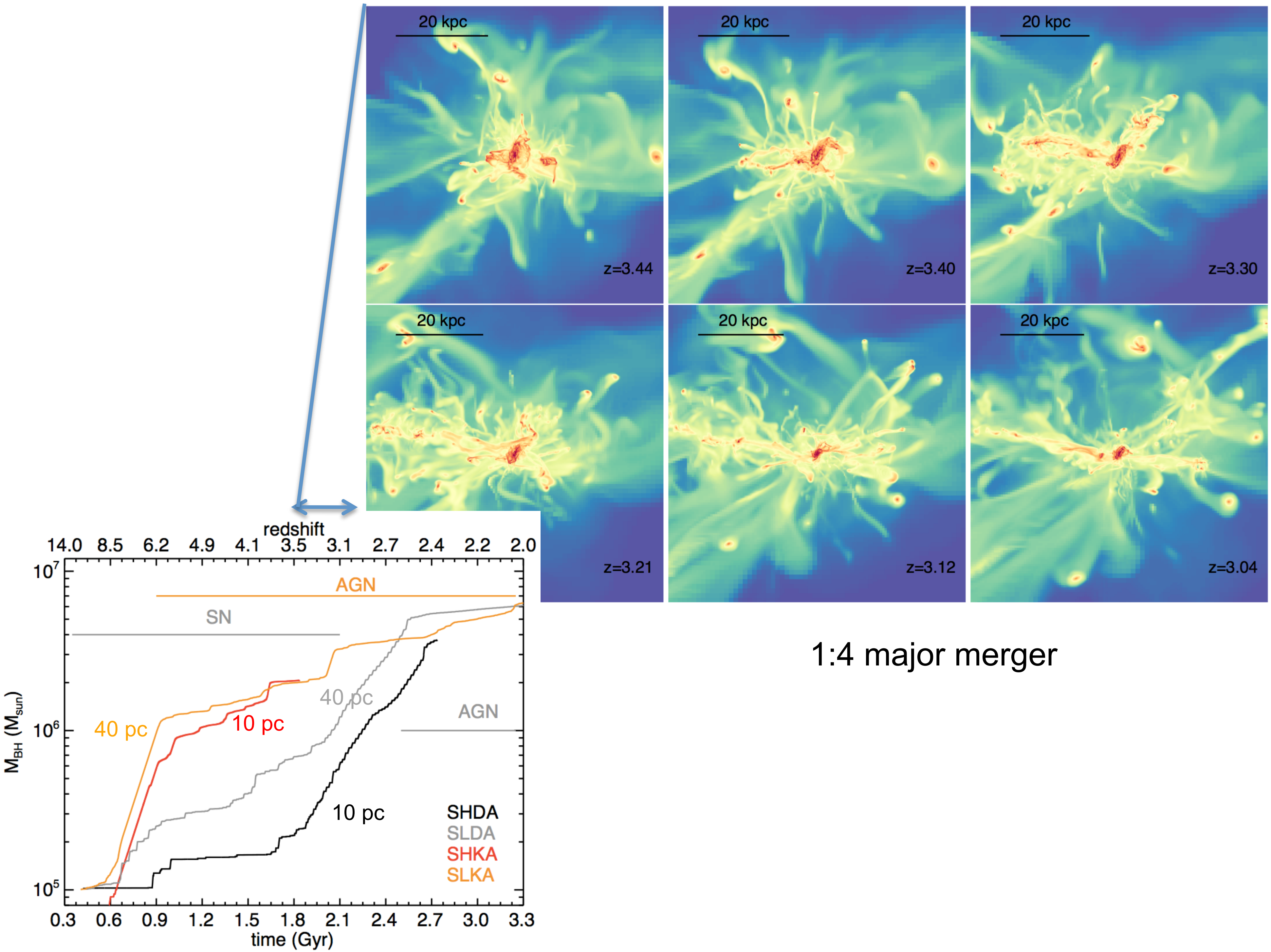
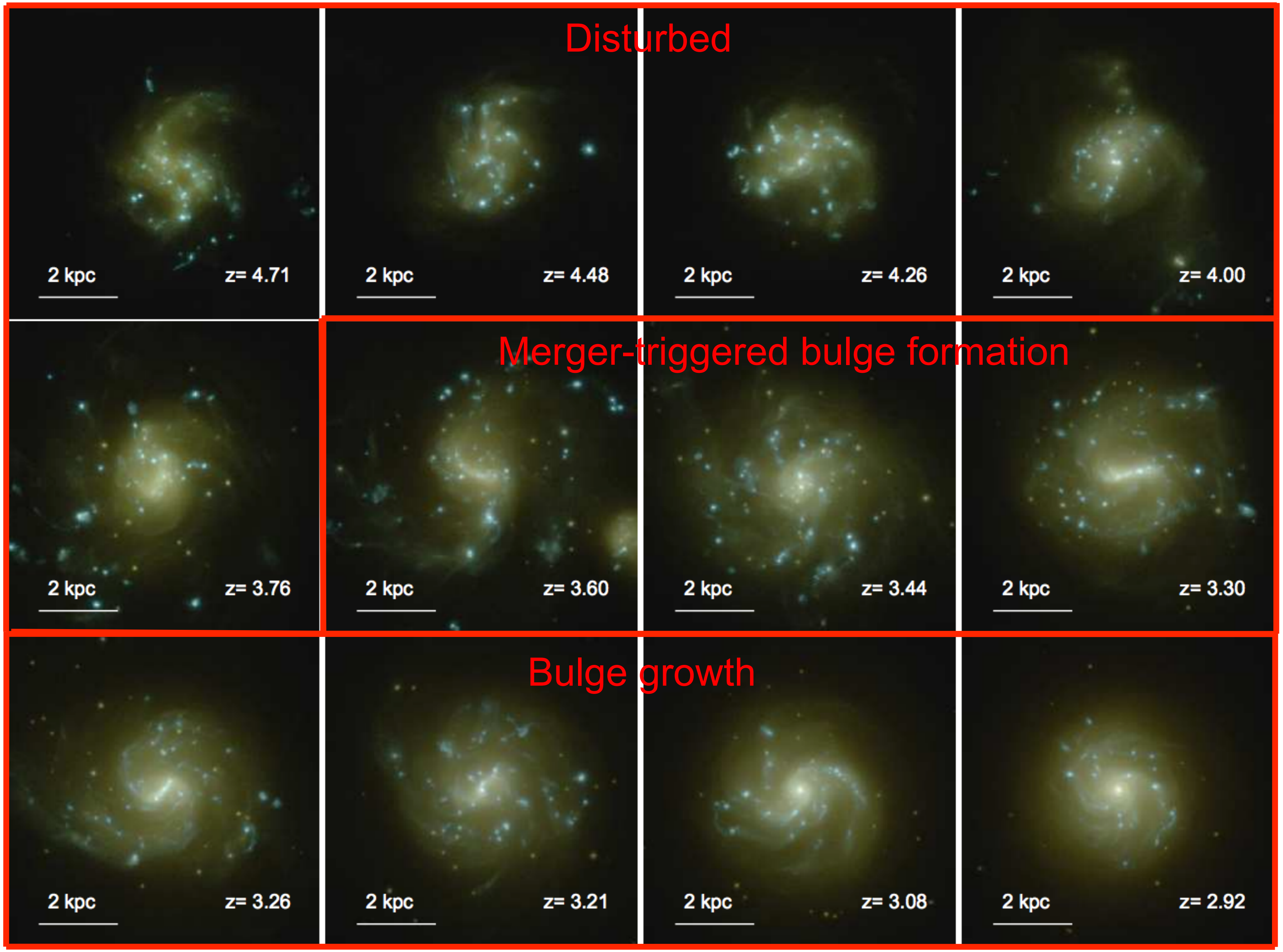


Dubois, Volonteri et al, 2015

See the bulge runaway growth of Keller et al, 2016



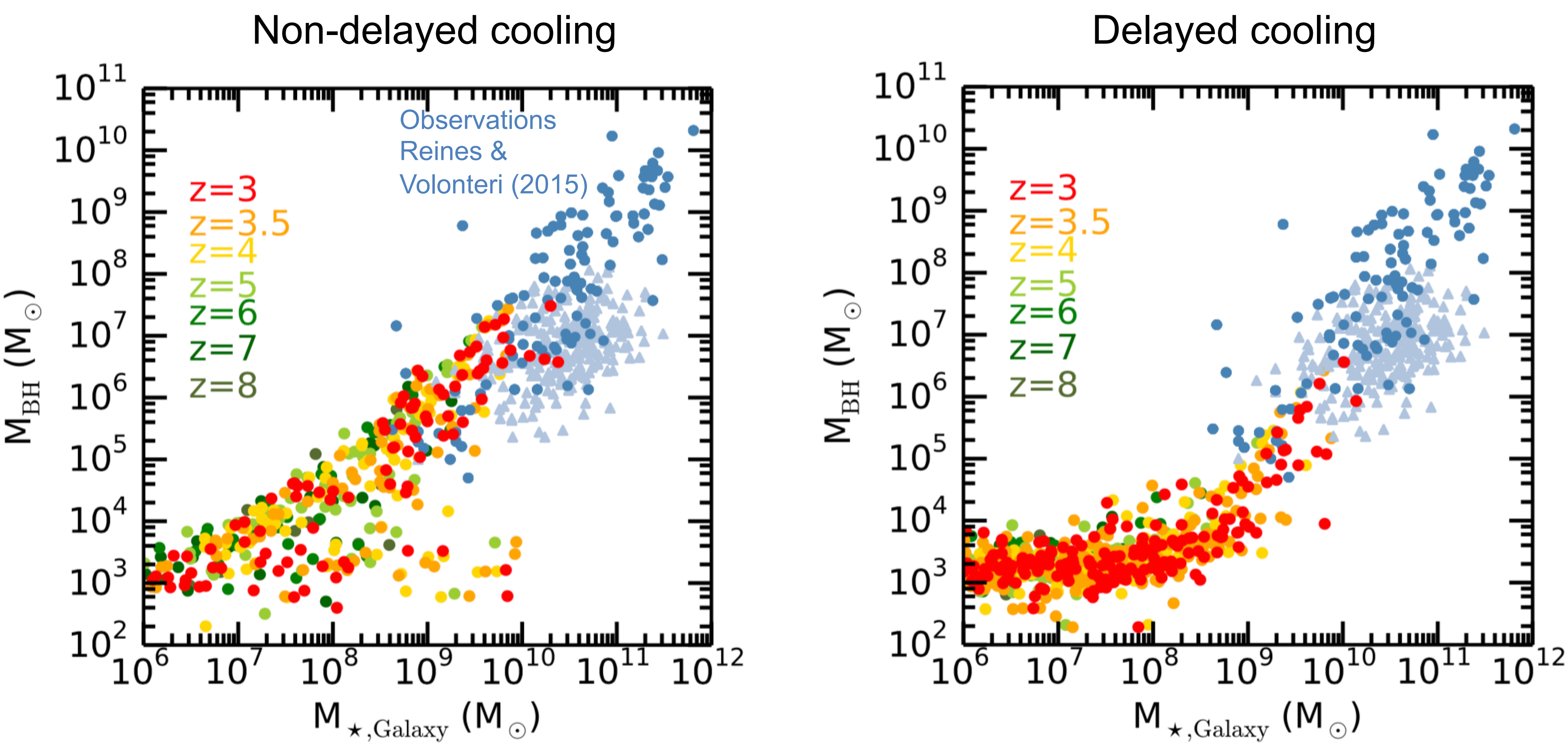
1:4 major merger



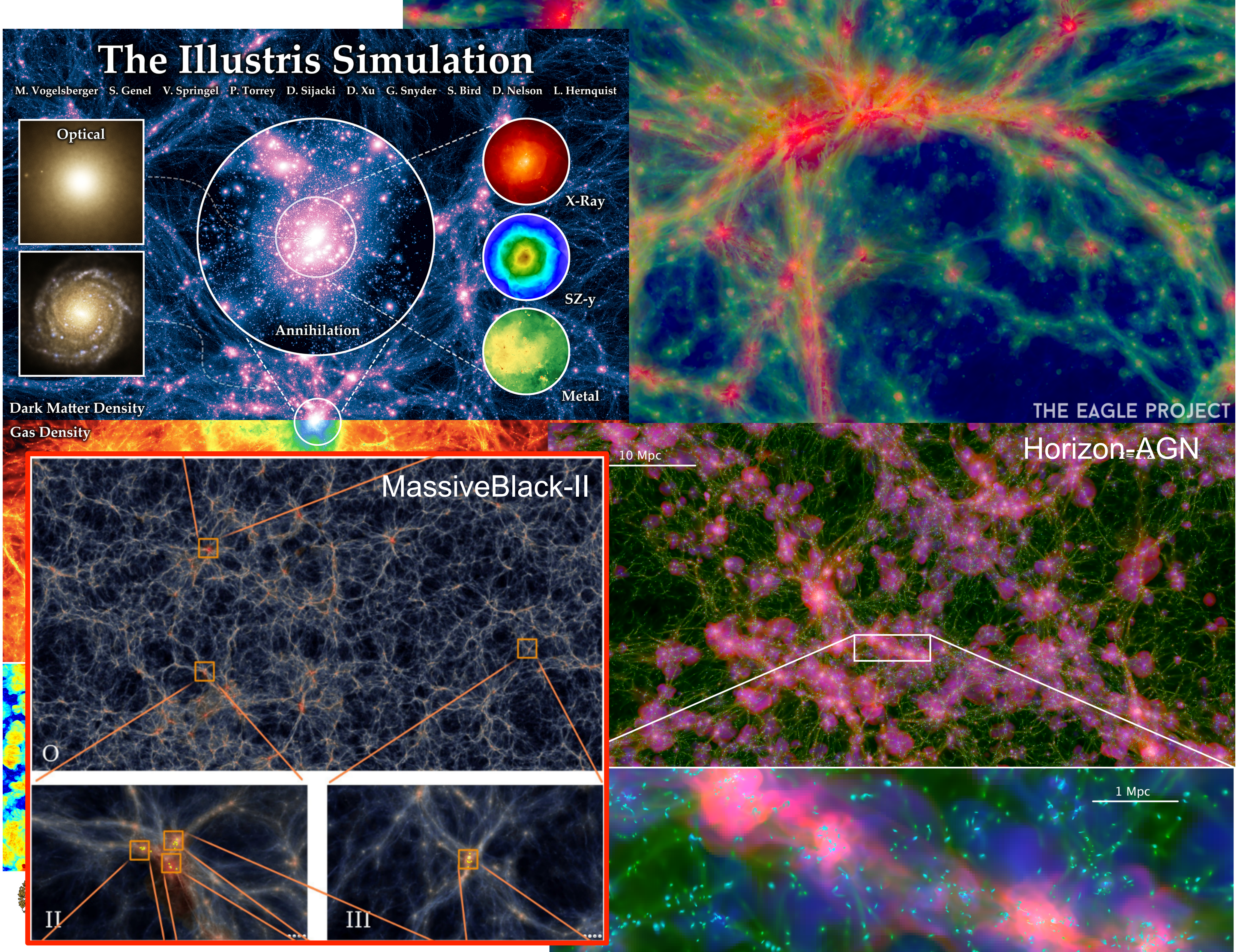
Disturbed
Merger-triggered bulge formation
Bulge growth
2 kpc
z= 4.71
2 kpc
z= 4.48
2 kpc
z= 4.26
2 kpc
z= 4.00
2 kpc
z= 3.76
2 kpc
z= 3.60
2 kpc
z= 3.44
2 kpc
z= 3.30
2 kpc
z= 3.26
2 kpc
z= 3.21
2 kpc
z= 3.08
2 kpc
z= 2.92

Confirmed in a statistical sense

10 Mpc volume with 80 pc spatial resolution
Using pop III BH seeding

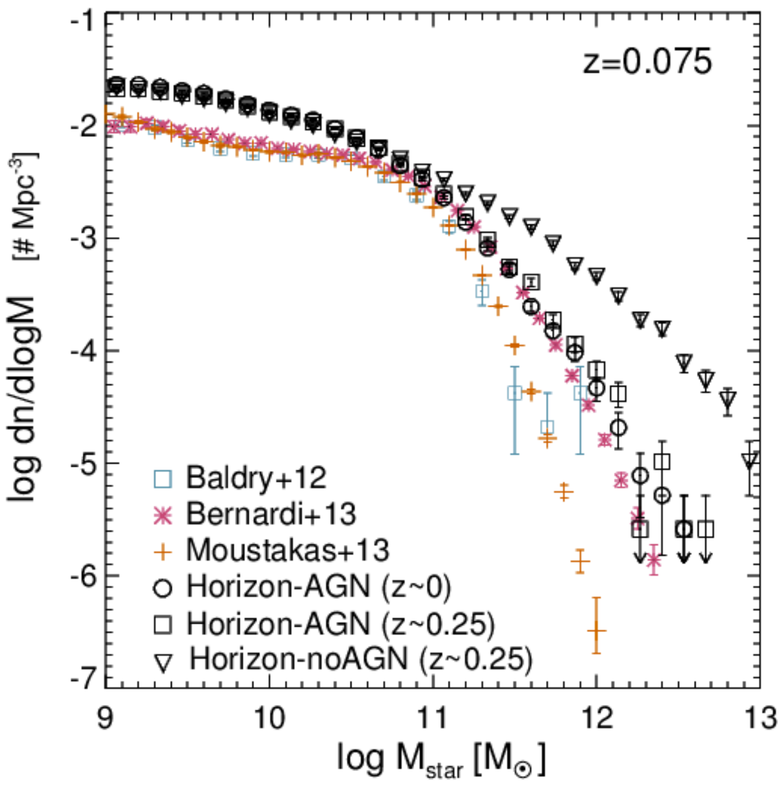


Habouzit et al, in prep.

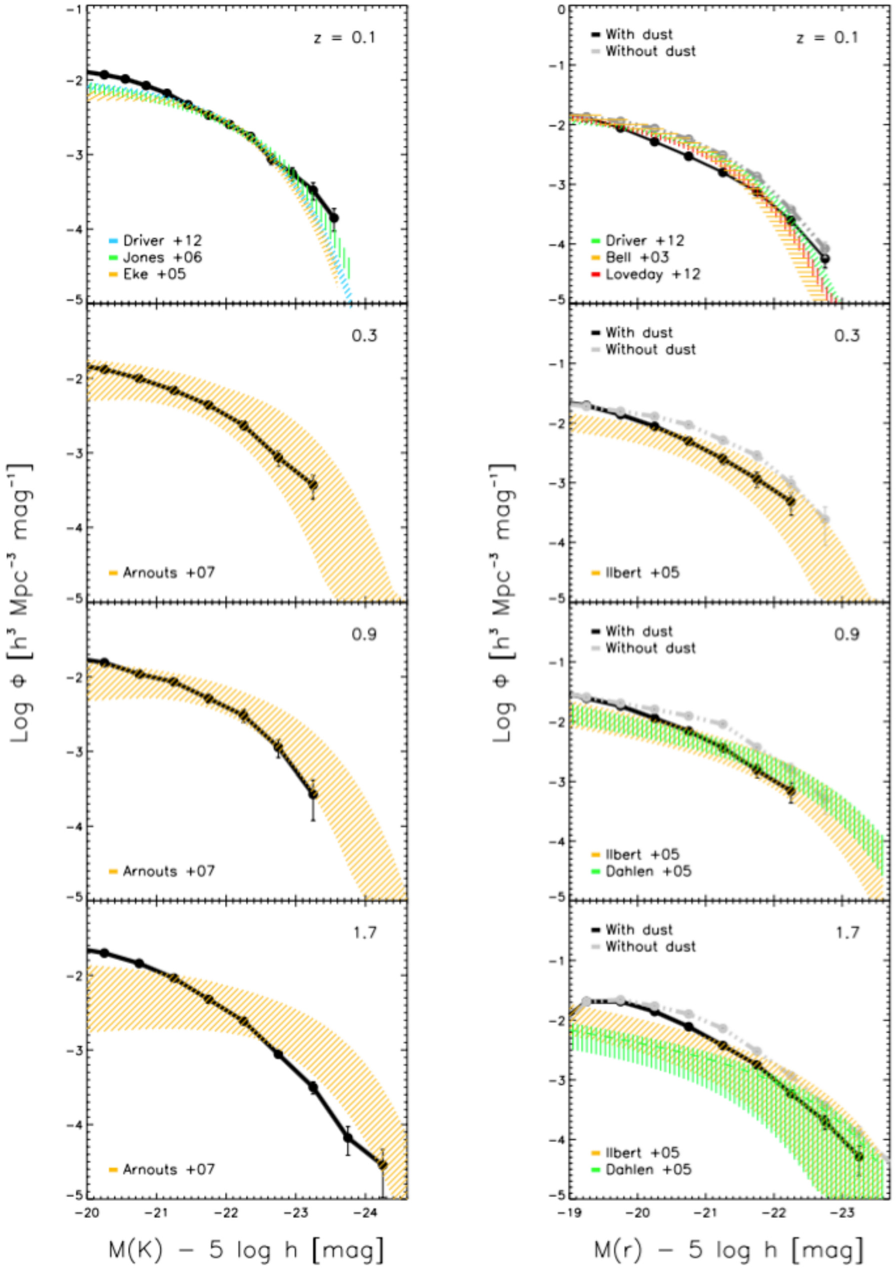

The Illustris Simulation
M. Vogelsberger S. Genel V. Springel P. Torrey D. Sijacki D. Xu G. Snyder S. Bird D. Nelson L. Hernquist
Optical
X-Ray
SZ-y
Annihilation
Metal
Dark Matter Density
Gas Density
THE EAGLE PROJECT
Horizon-AGN
10 Mpc
1 Mpc
MassiveBlack-II
O
II
III

Luminosity/mass function in Horizon-AGN

Log number density of galaxies



Log stellar mass



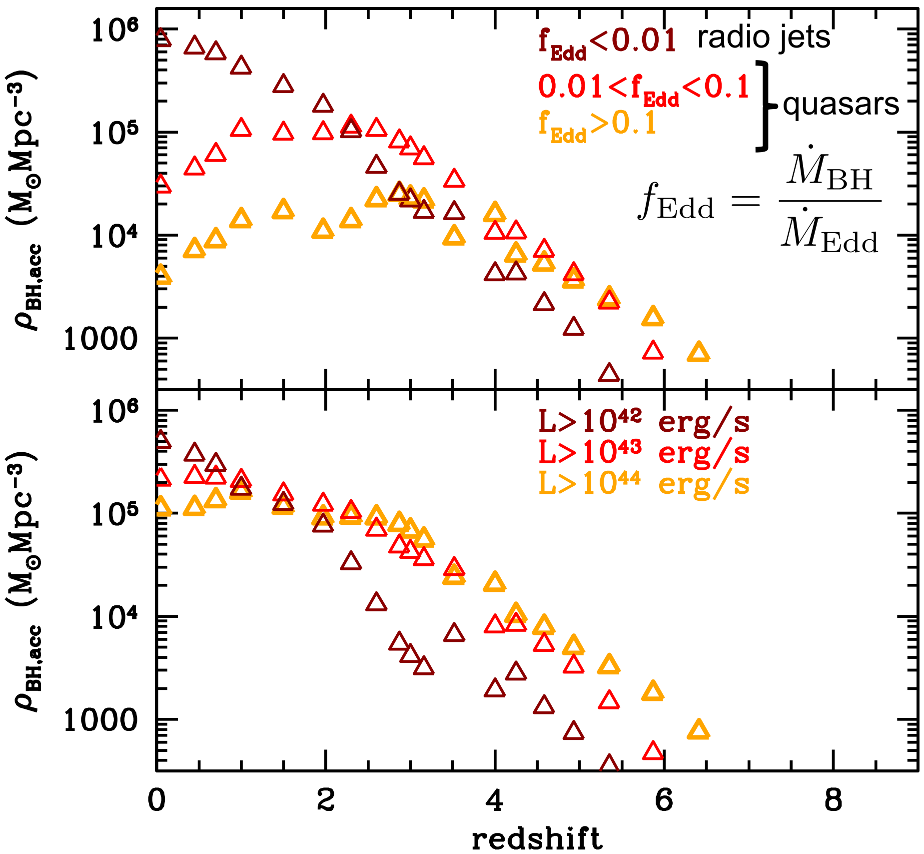
K-band magnitude

r-band magnitude

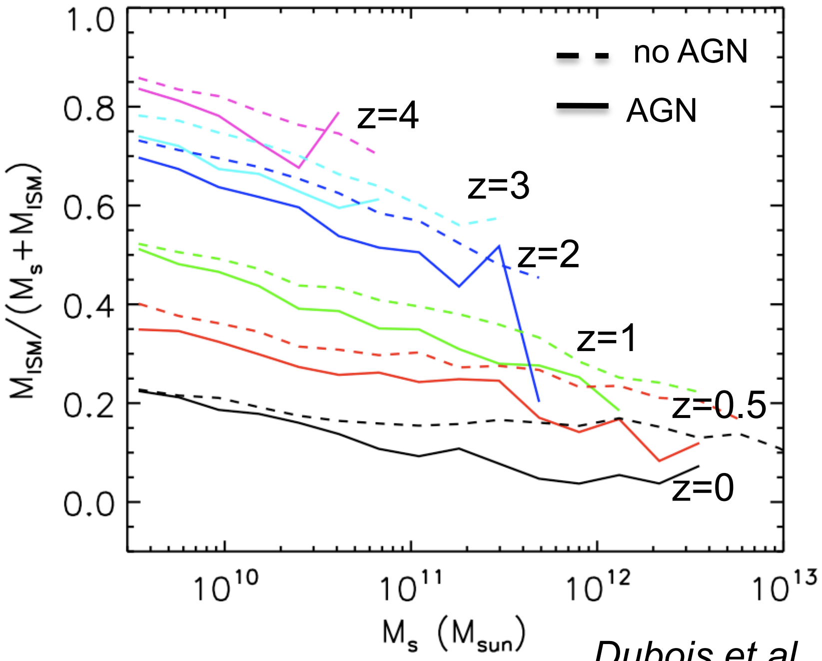
Kaviraj, Laigle et al, in prep.

Radio mode or quasar mode ?

BHs in Horizon-AGN



Volonteri et al, 2016
See also:
Sijacki et al, 2007; Di Matteo et al, 2008;
Dubois et al, 2012

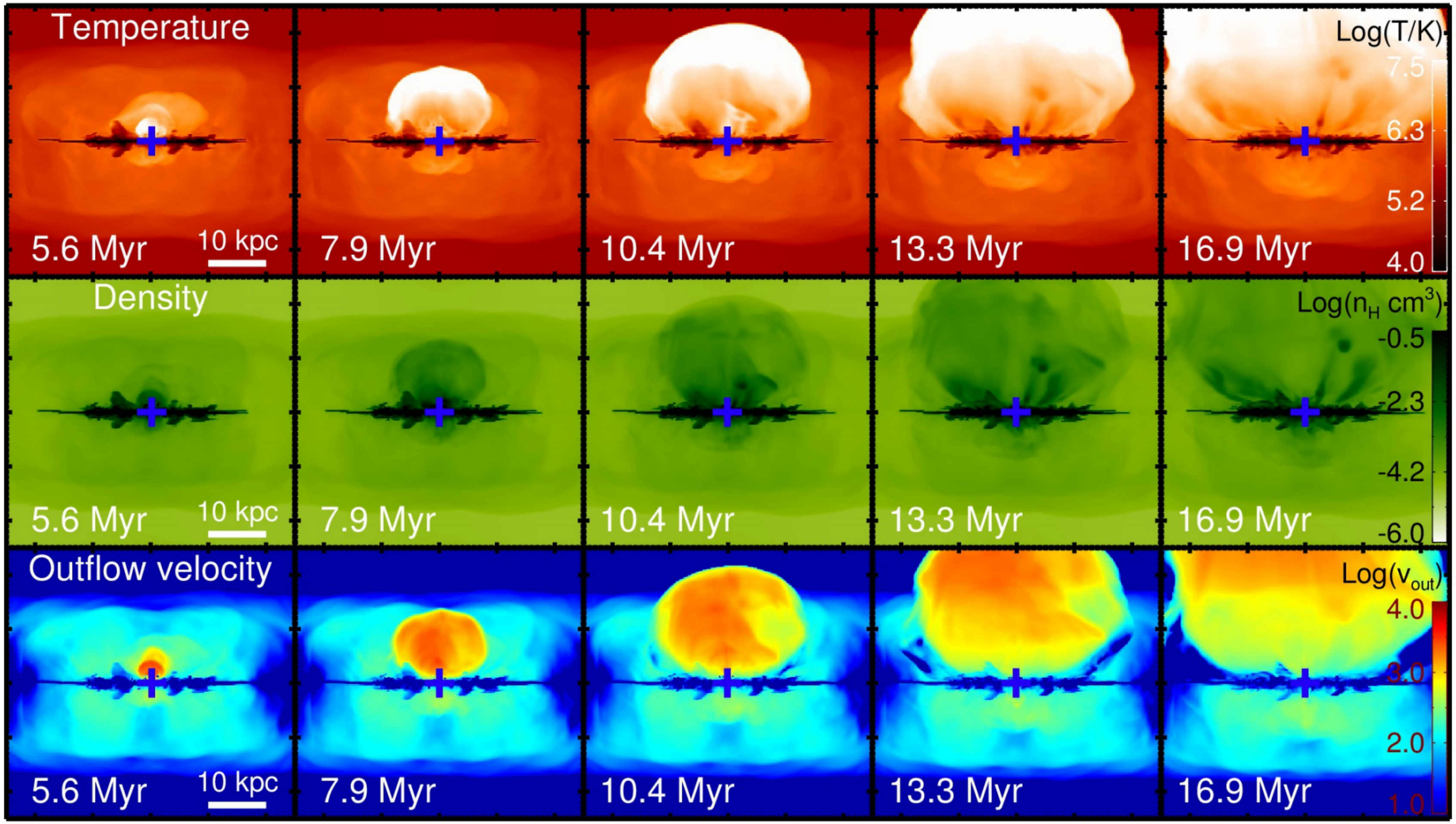


Dubois et al, 2012

Galaxies are gas-rich at high-redshift

Star formation and feedback consumes/ removes/ prevents from collapsing the gas

Quasar mode AGN do not destroy discs



Gabor & Bournaud, 2014

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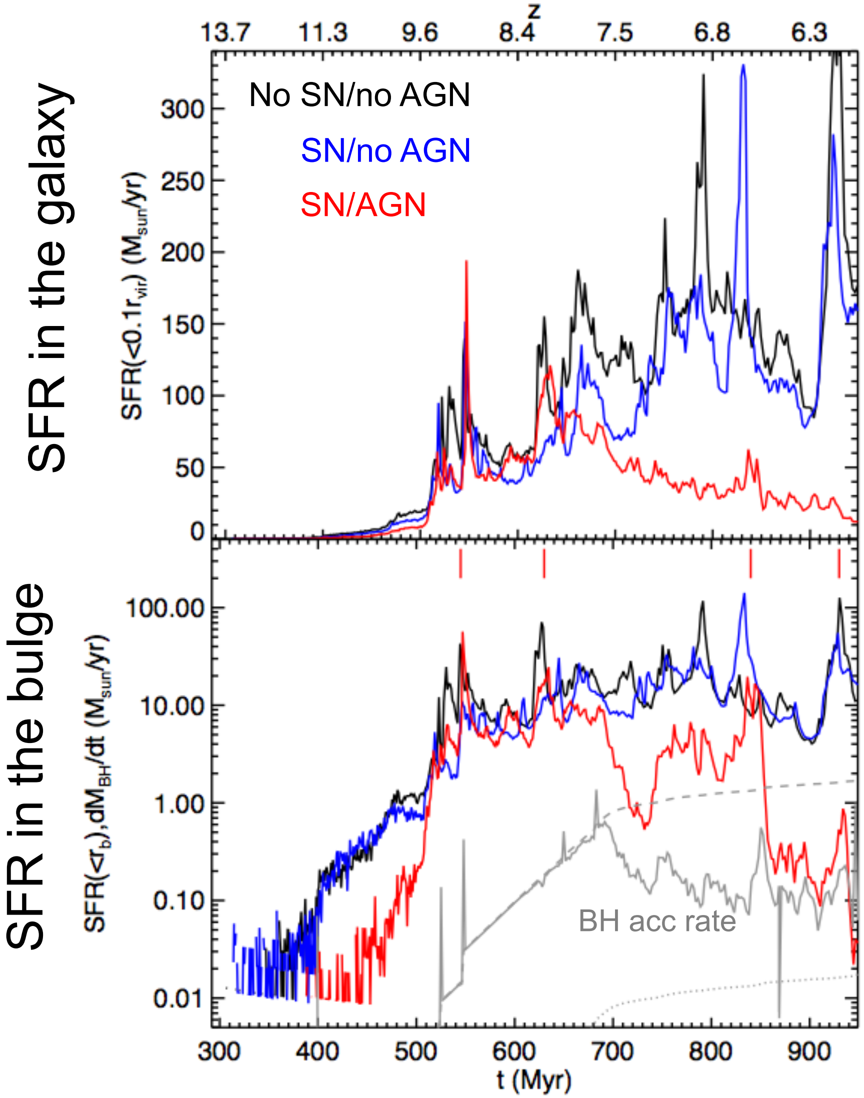
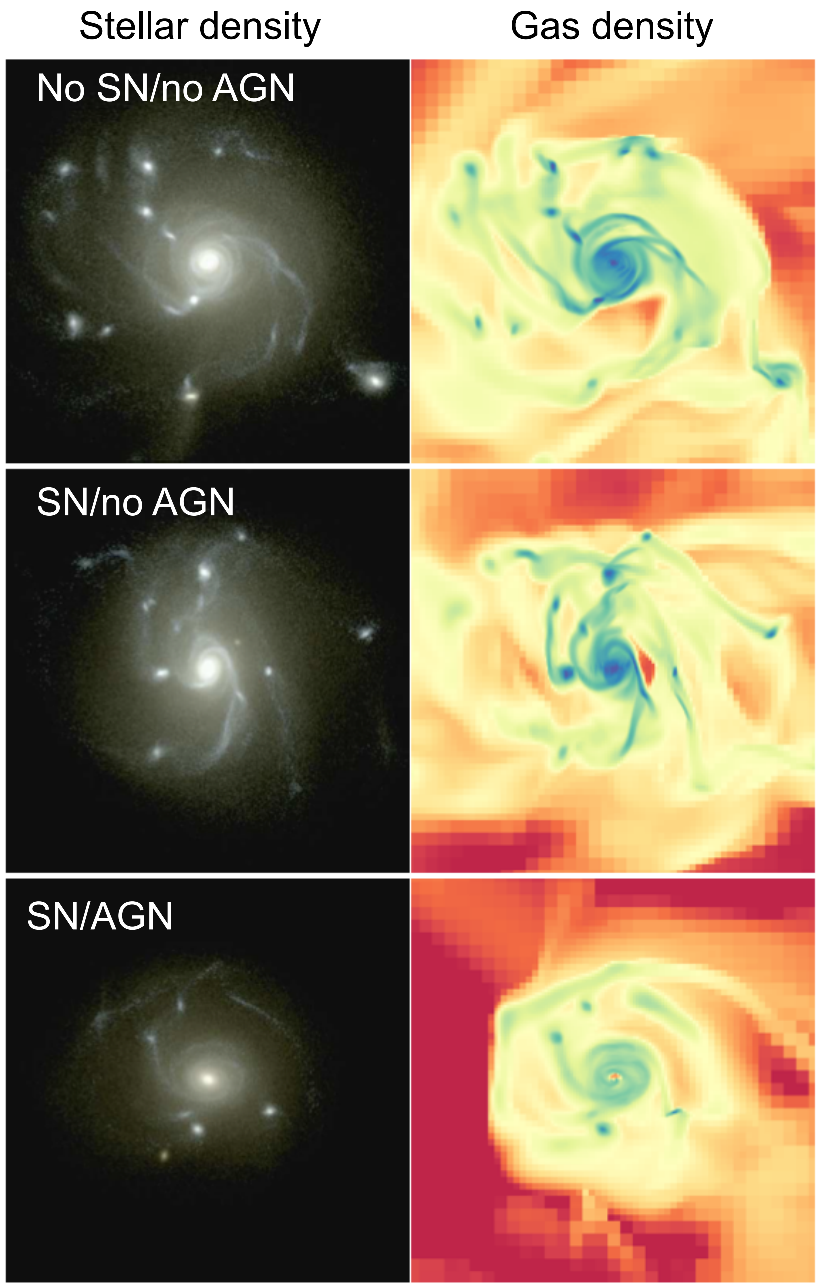
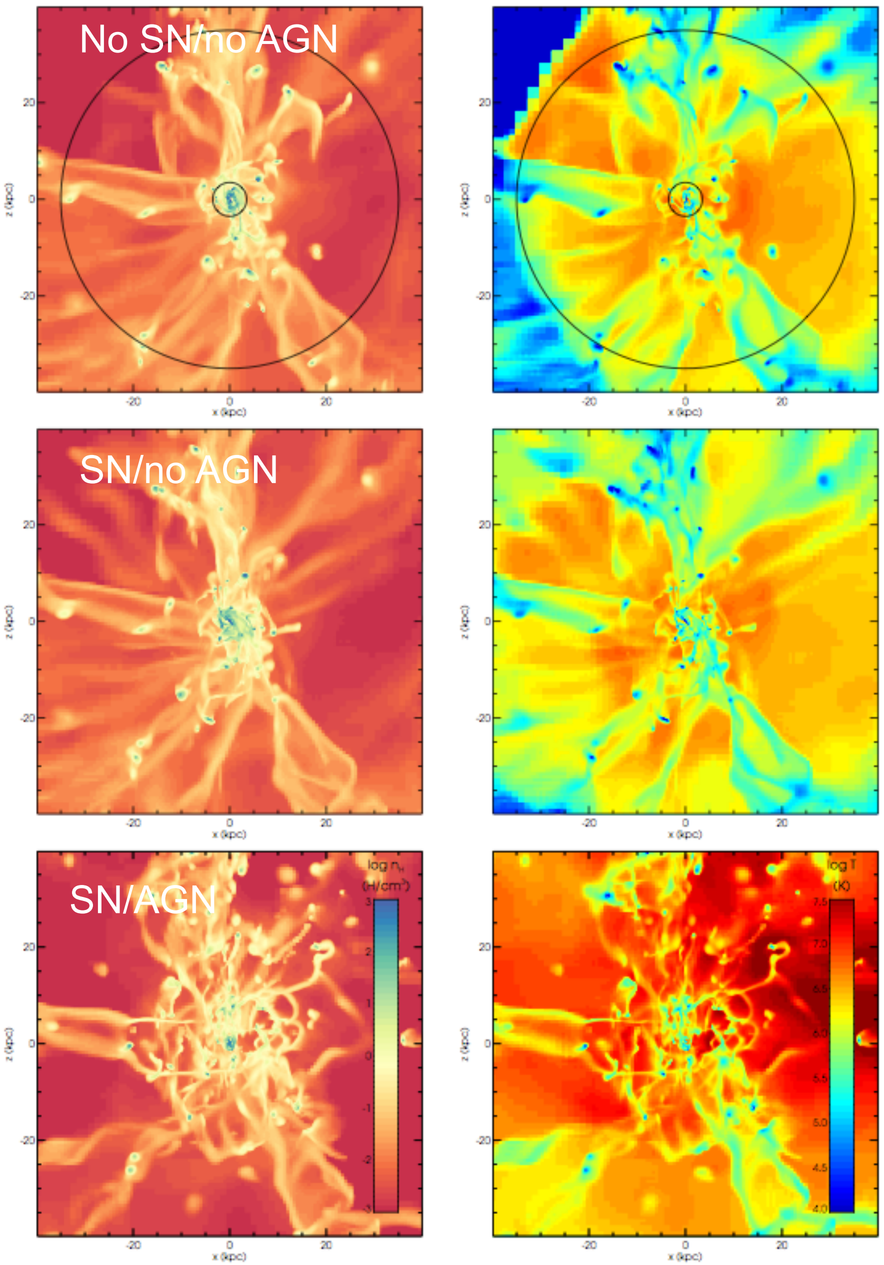




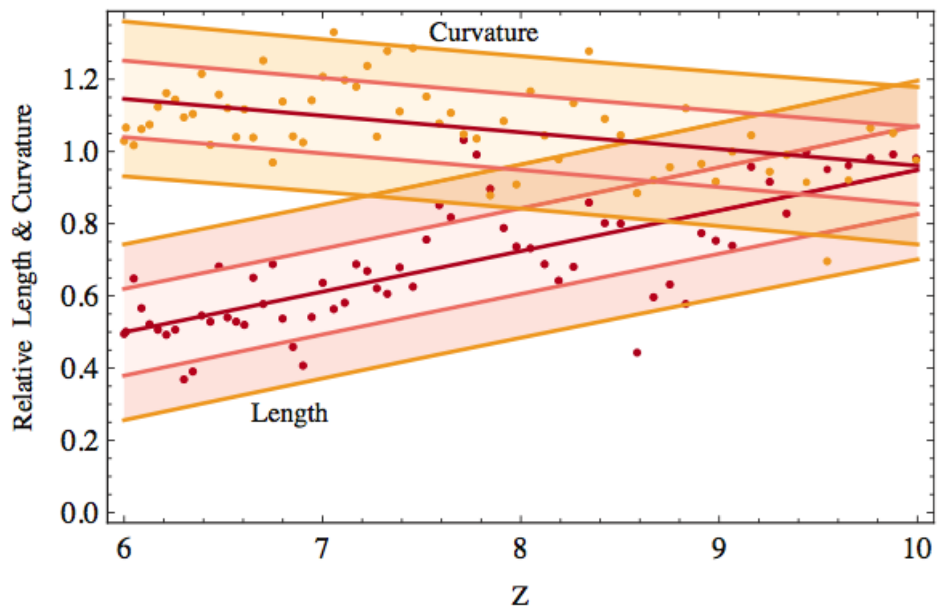
Dubois, Pichon et al, 2013

Quasar mode AGN strangulate galaxies (and can blow cold flows away)



Gas is driven out hot from the central galaxy due to AGN.

Cold filaments are repelled from the halo. Their structure is strongly perturbed



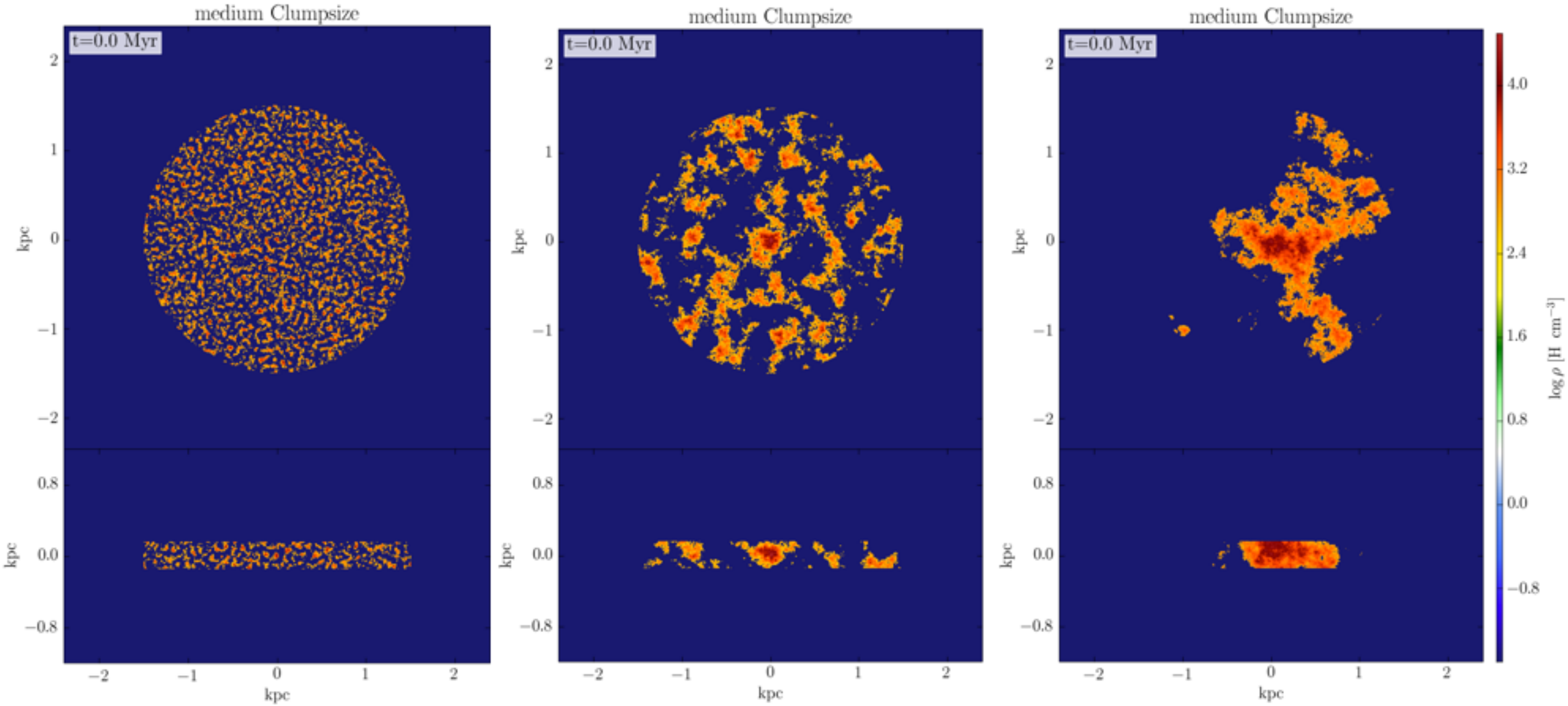
Dubois, Pichon et al., 2013

Shining a quasar in a multiphase medium

Rebekka Bieri

Log Normal pdf for gas density
Power spectrum $k^{-5/3}$ (and different cloud size)
ICs from Wagner & Bicknell (2011)

Galaxy mass is 2.10^{10} M_{sun}
With 100% gas (no DM, no stars)
Resolution is 5 pc in dense clouds



L_{cloud}=50 pc L_{cloud}=300 pc L_{cloud}=1 kpc

Bieri et al, in prep.

Radiation hydrodynamics

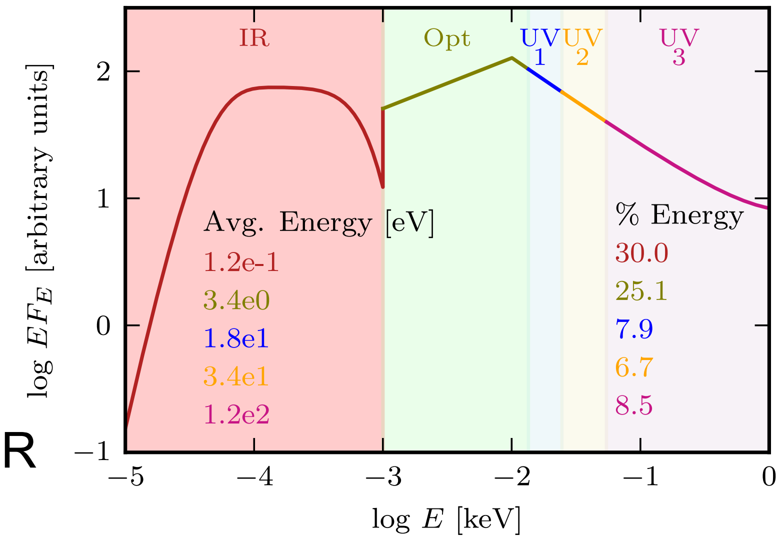
- Uses moment method with M1 closure to solve radiative transfer in RAMSES (Rosdahl et al, 2013, Rosdahl & Teyssier 2015)
- Solving non-equilibrium evolution of ionisation fractions of H, HeI, HeI

- Radiation Pressure + diffusion of multi-scattering IR radiation included
- Dust opacities $\kappa_{\mathrm{D,UV}} = 1000\,\mathrm{g\,cm^{-2}}$, $\kappa_{\mathrm{D,IR}} = 10\,\mathrm{g\,cm^{-2}}$, $\kappa_{\mathrm{D}} = 0 \text{ if } \mathrm{T} > 10^5\,\mathrm{K}$

- Solar metallicity with all metals in dust content
- Two AGN luminosities 10^{46} erg/s & 10^{43} erg/s

- Reduced speed of light approximation c_{red}=0.005 c (Gnedin & Abel 2001)

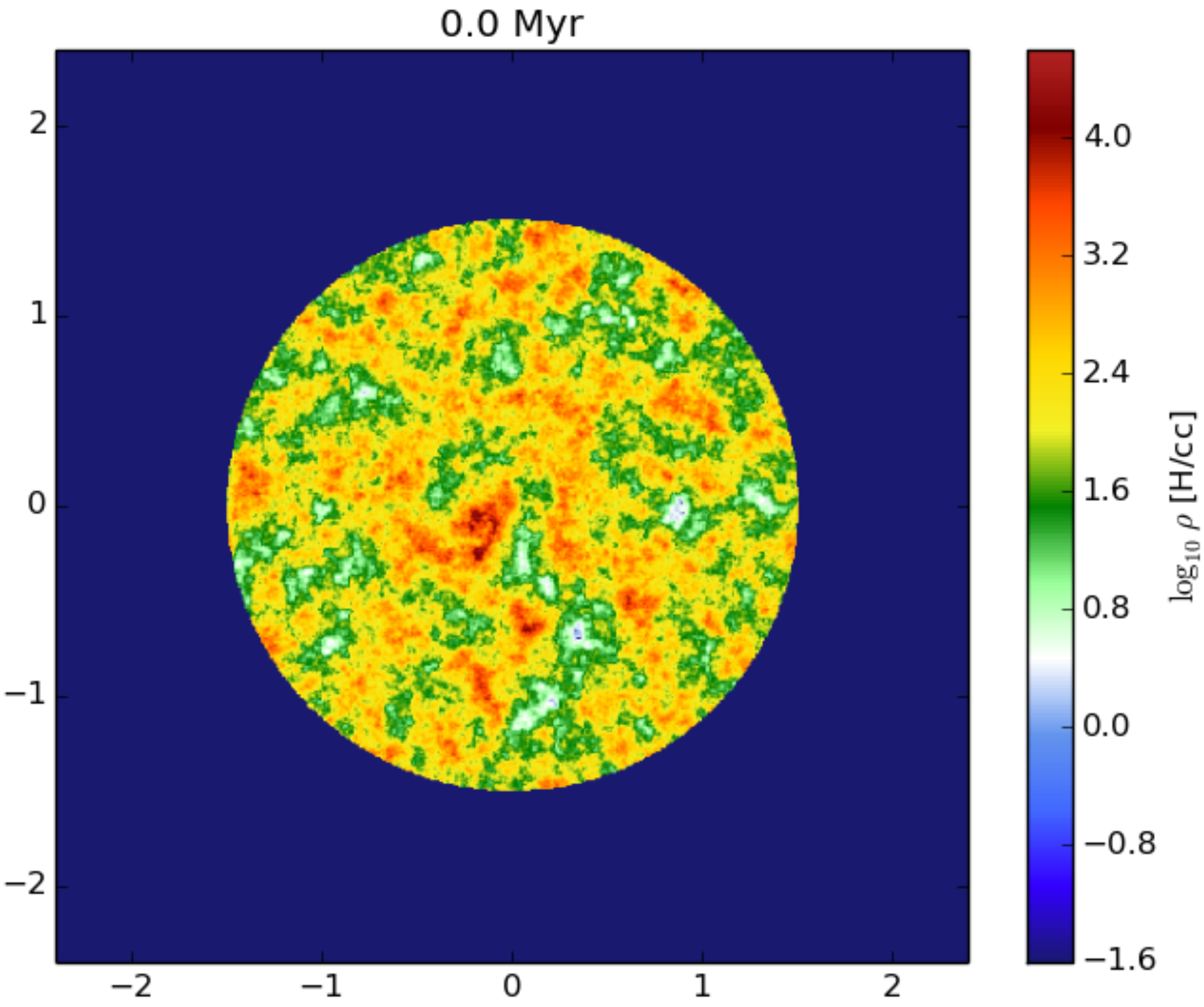
5 photon groups

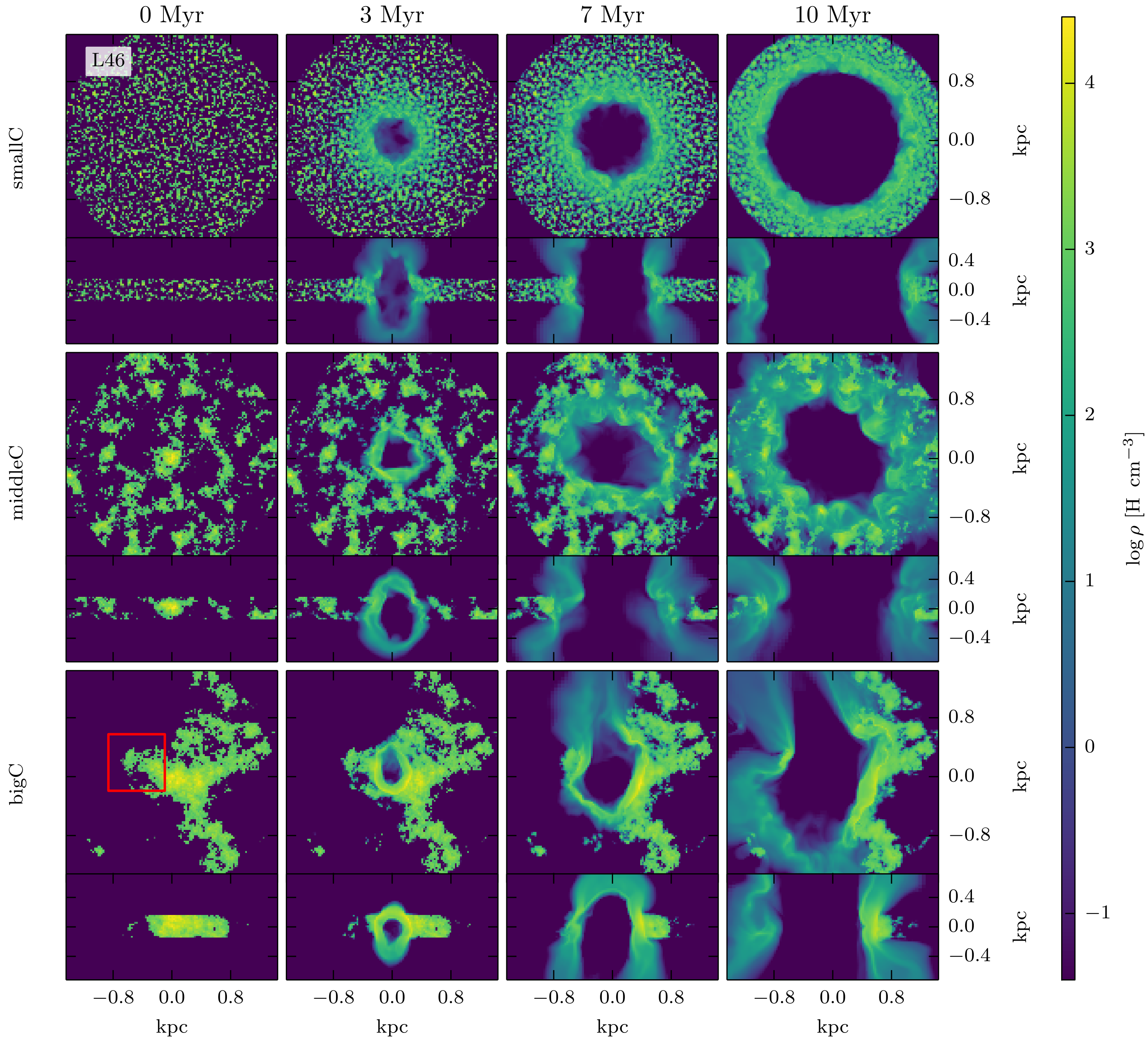


Sazonov+ 2004

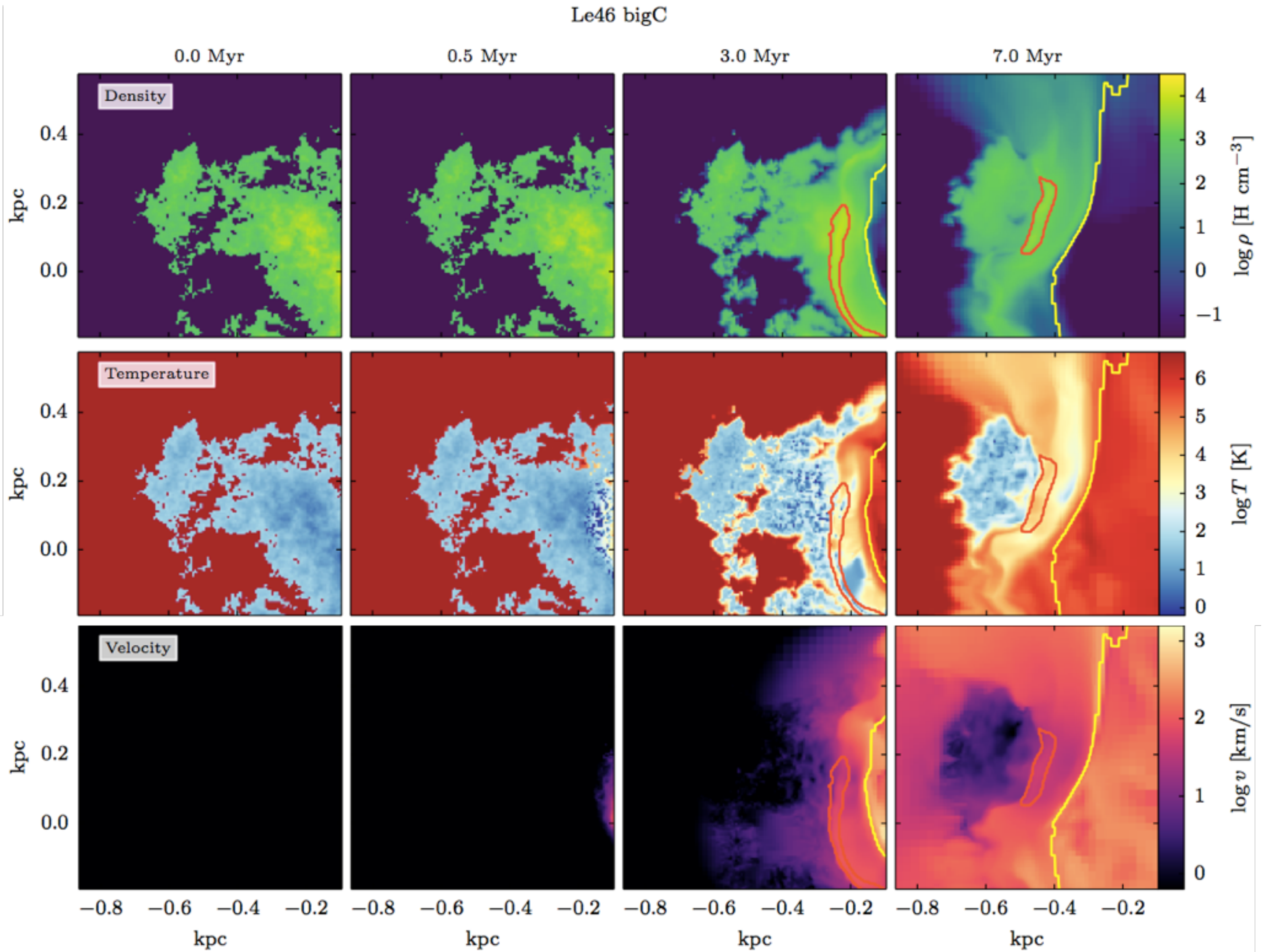
Big Caveat:
No gravity
No cooling
No SF

Medium cloud size
10^{46} erg/s

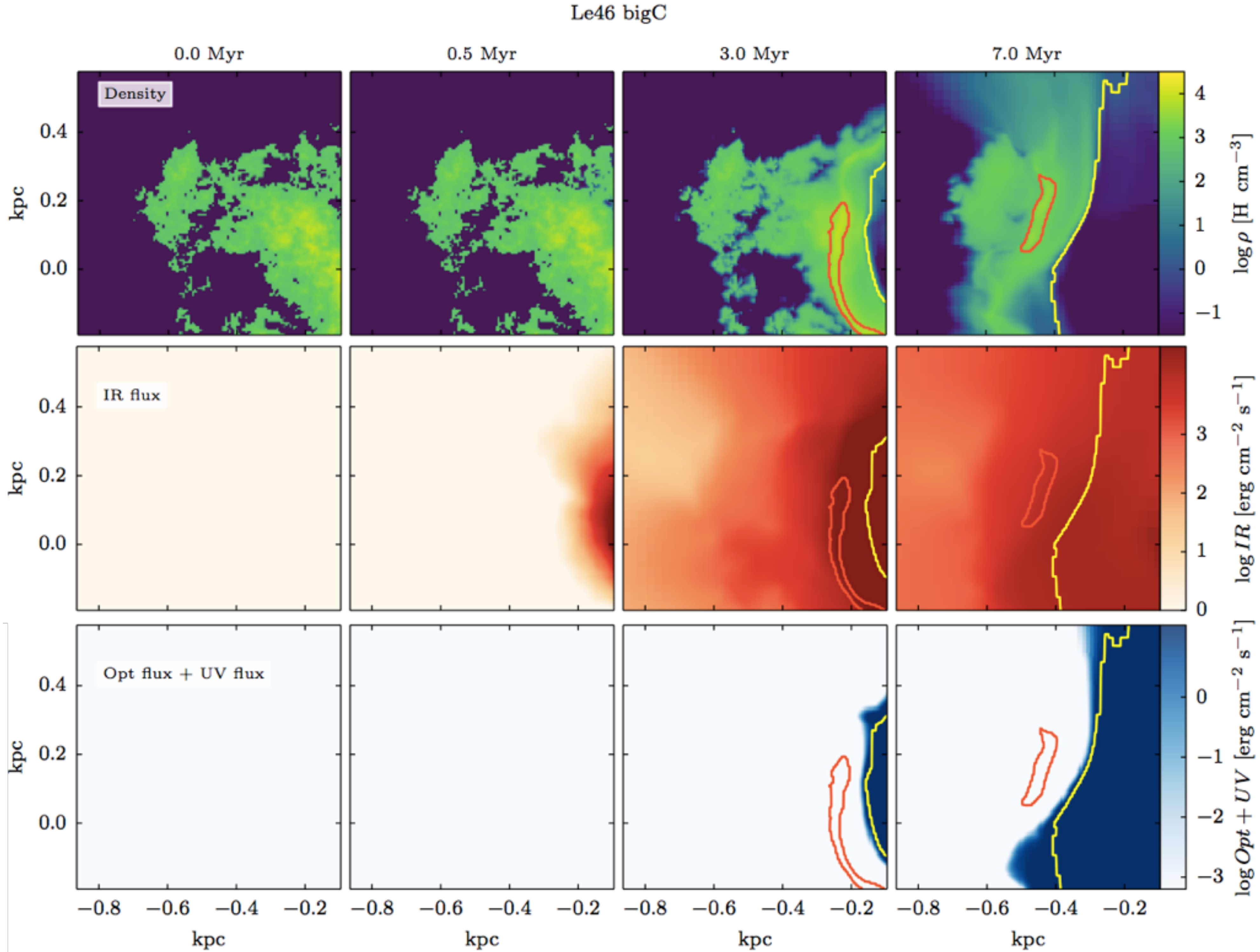




0 Myr
3 Myr
7 Myr
10 Myr
L46
smallC
middleC
bigC
0.8
0.0
−0.8
0.4
0.0
−0.4
kpc
−0.8
0.0
0.8
kpc
log ρ [H cm−3]
4
3
2
1
0
−1



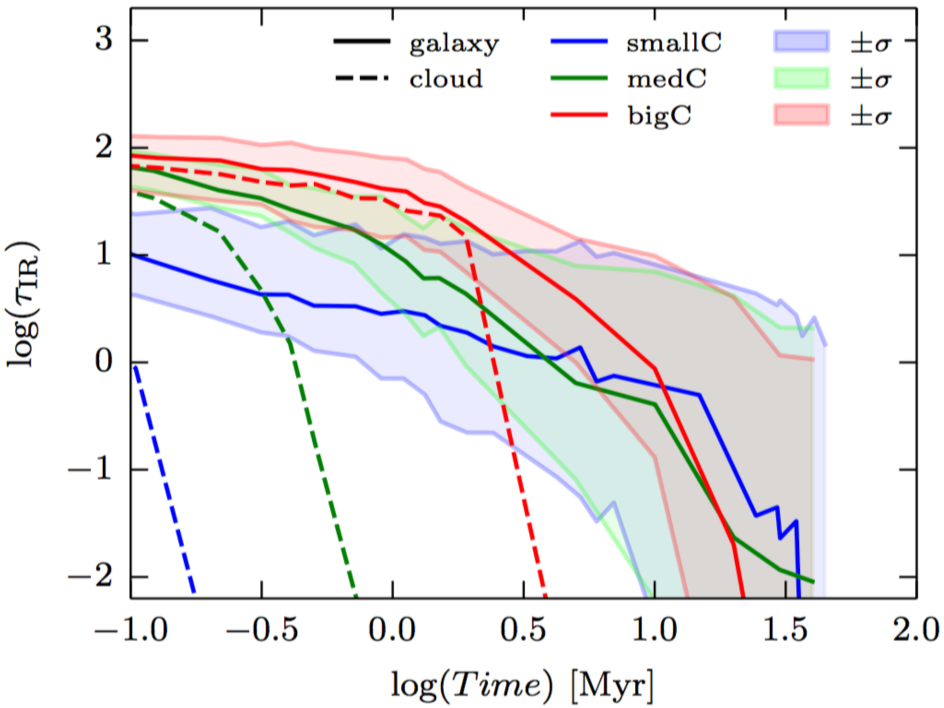
Le46 bigC
0.0 Myr
0.5 Myr
3.0 Myr
7.0 Myr
Density
Temperature
Velocity
kpc
0.4
0.2
0.0
−0.8
−0.6
−0.4
−0.2
$\log \rho$ [H cm^{-3}]
$\log T$ [K]
$\log v$ [km/s]



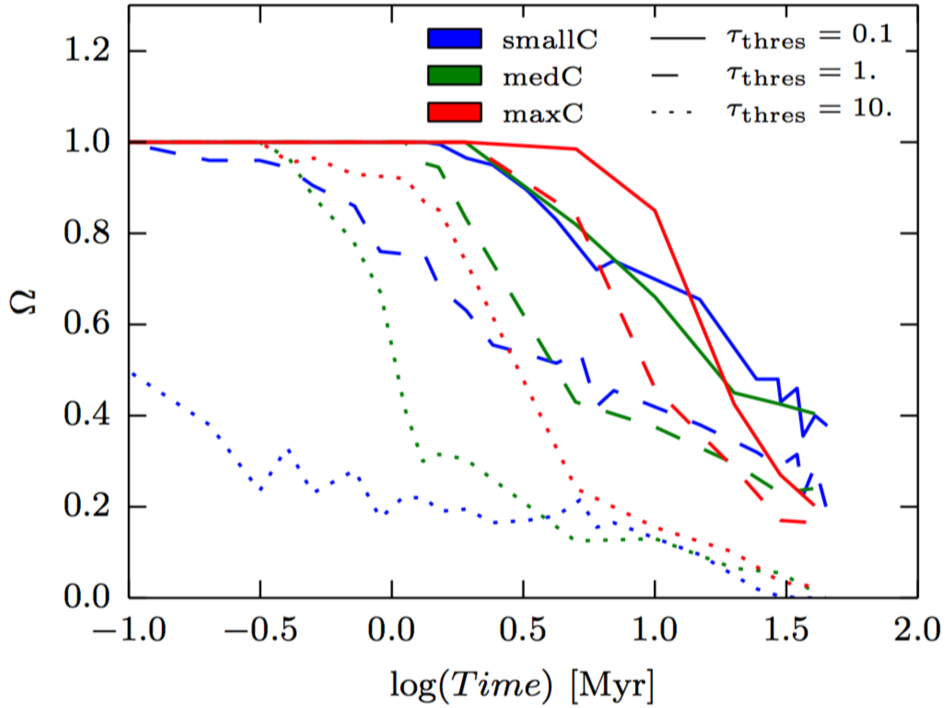
Le46 bigC
0.0 Myr
0.5 Myr
3.0 Myr
7.0 Myr
Density
IR flux
Opt flux + UV flux
kpc
0.4
0.2
0.0
−0.8
−0.6
−0.4
−0.2
log ρ [H cm⁻³]
log IR [erg cm⁻² s⁻¹]
log Opt + UV [erg cm⁻² s⁻¹]

Optical depth and cloud break-up

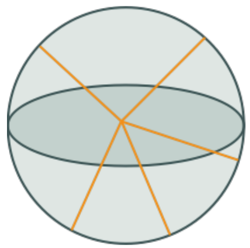
Optical depth



Fraction of solid angle with $\tau > \tau_{\rm thres}$

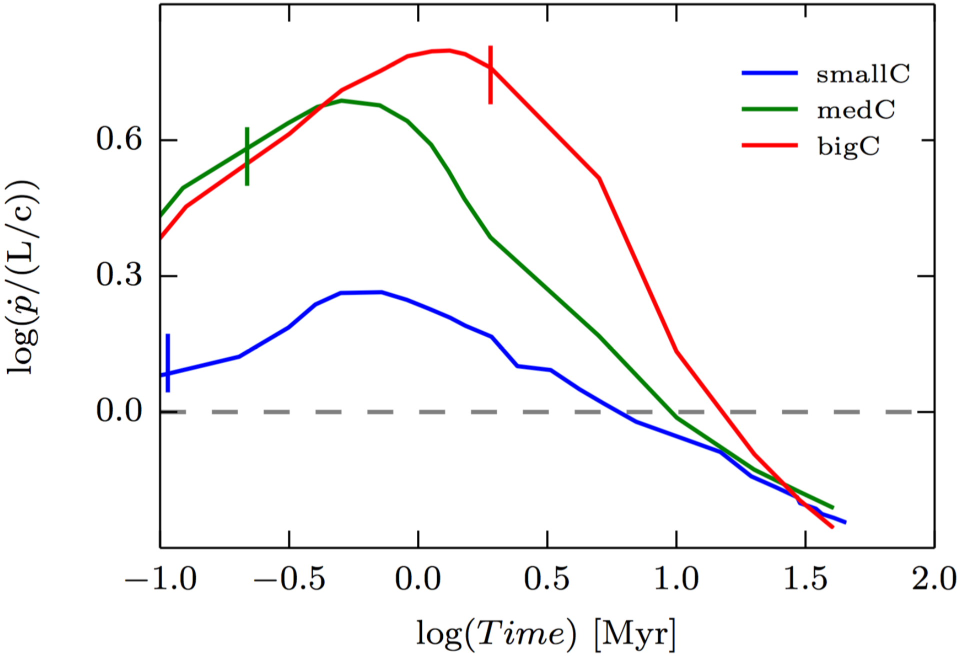


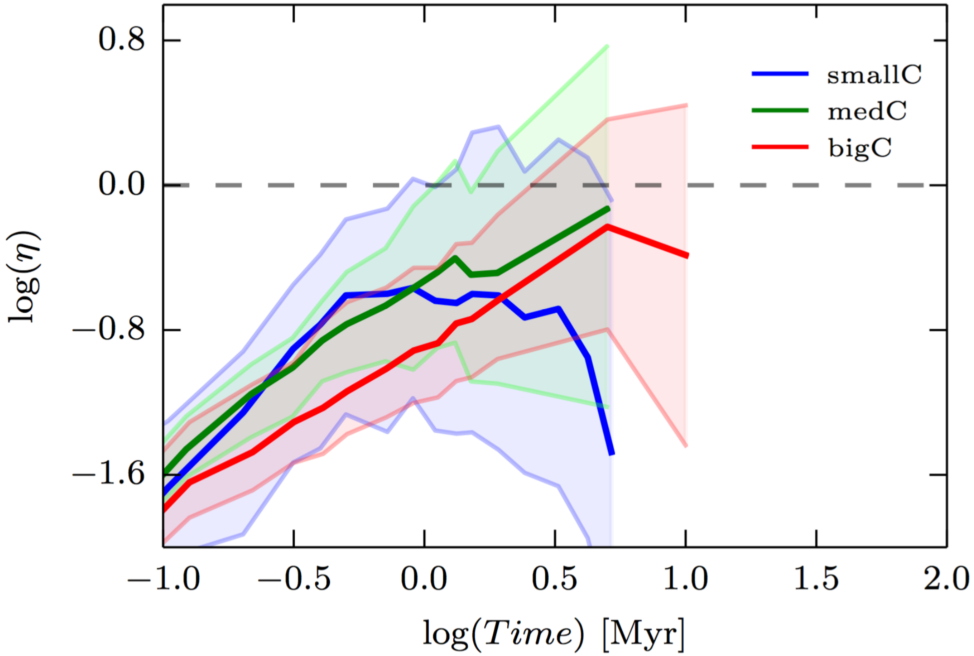
500 rays are casted to measure $\tau_{\rm IR}$

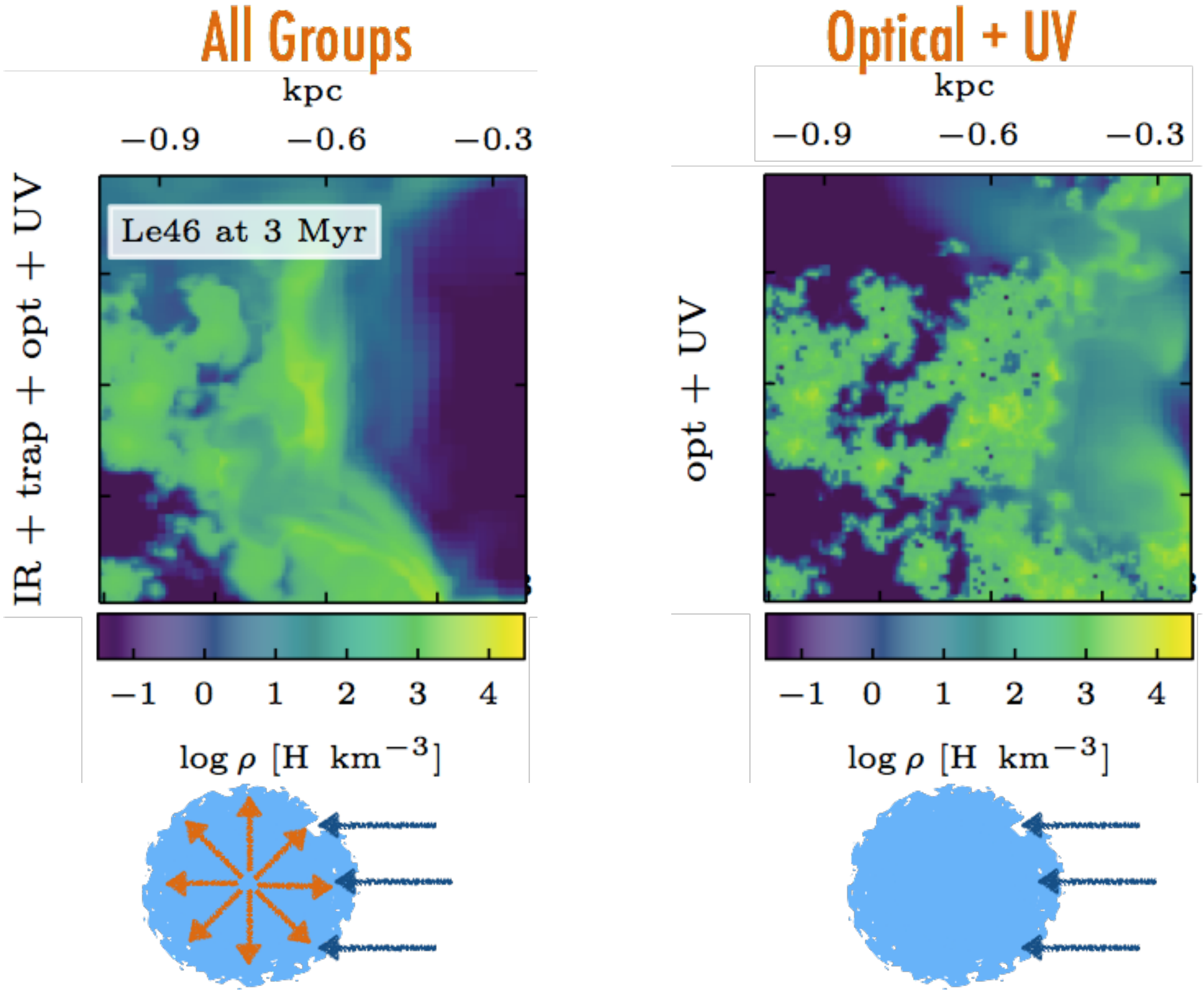


Mechanical advantage

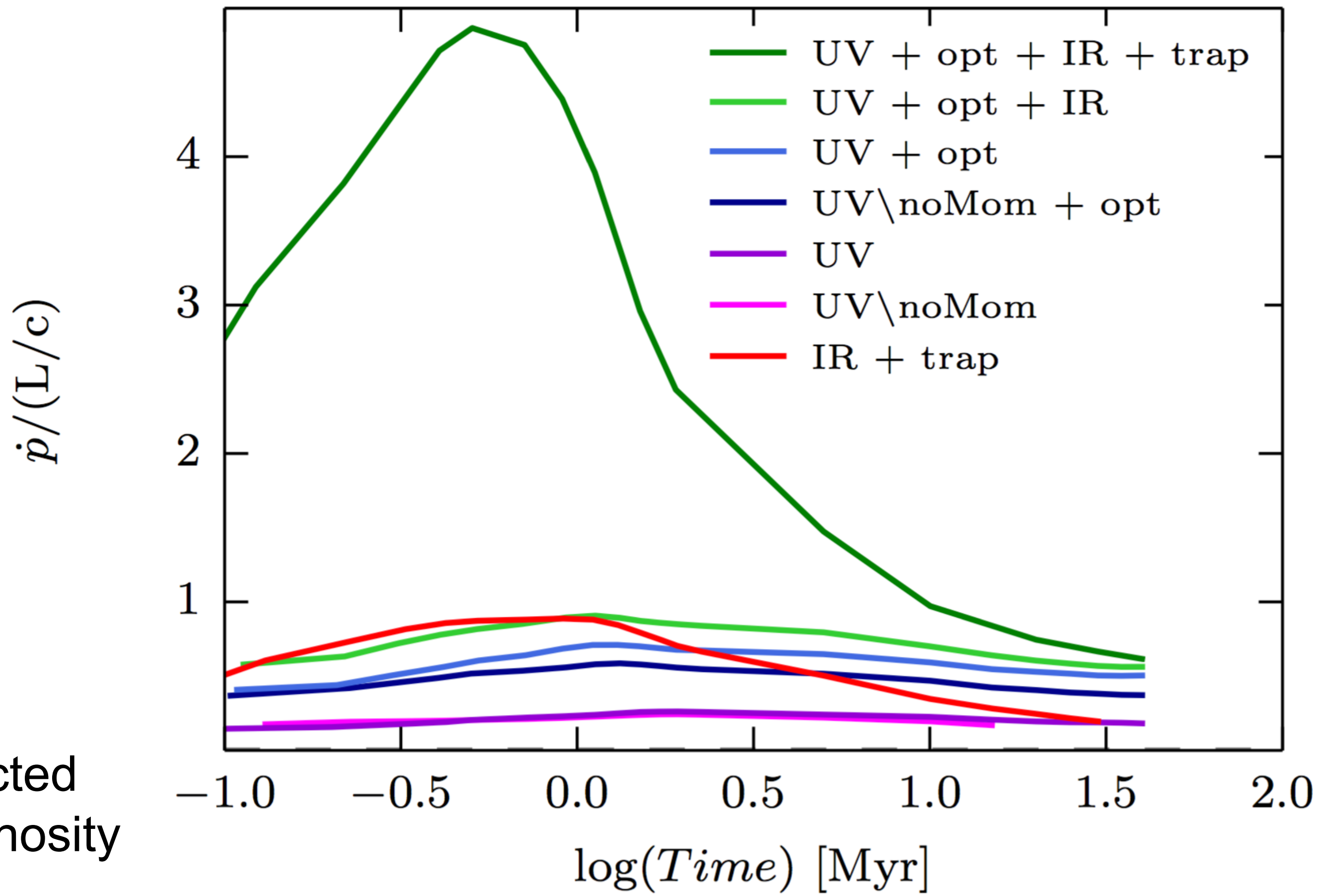
$$\dot{p} = (1 + \eta\tau_{\rm IR})\frac{L}{c}$$






All Groups
Optical + UV
kpc
−0.9
−0.6
−0.3
Le46 at 3 Myr
IR + trap + opt + UV
opt + UV
−1
0
1
2
3
4
log ρ [H km−3]

Mechanical advantage considering different groups



L is the injected photon luminosity
Not L_{bol}

Summary

- BH growth at high redshift:
  - Fed by cosmic cold flows early on and by disc instabilities later on
  - SN feedback can suppress BH growth in high-redshift low-mass galaxies $M_{bulge}<10^9\ M_{sun}$ (or $V_{esc}>270$ km/s)

- Quasar mode with photons only:
  - Can drive winds because of IR multi-scattering
    - Though fewer scatters than theoretically inferred
  - Destroys the disc (need to be confirmed in more realistic set-up)